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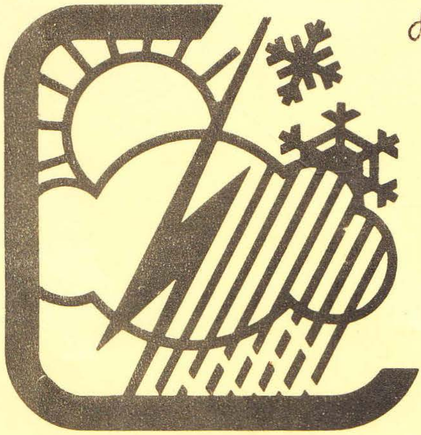

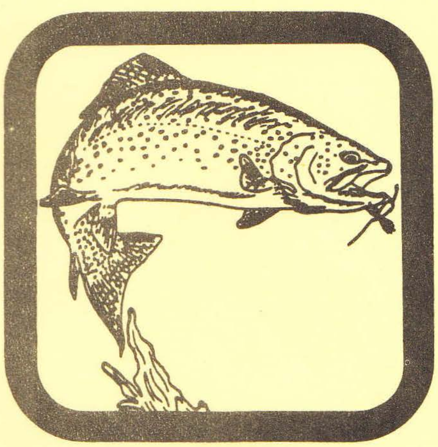

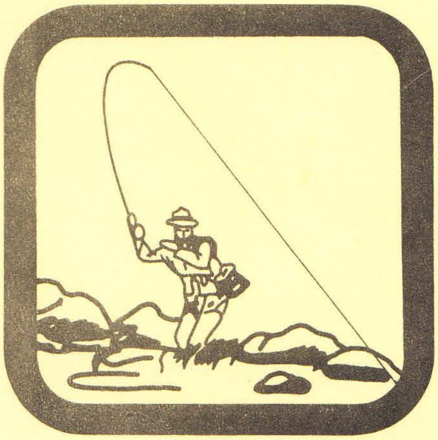

# GUIDE FOR PREDICTING SALMONID RESPONSE TO SEDIMENT YIELDS IN IDAHO BATHOLITH WATERSHEDS

NORTHERN REGION
INTERMOUNTAIN REGION
Wildlife Management

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U.S. FOREST SERVICE
NORTHERN REGION
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A working draft of this document entitled "A Method for Predicting Fish Response to Sediment Yields" was previously released in August 1980. This document is a further refinement of the methodology to explain concepts and procedures.

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## EXECUTIVE SUMMARY

The Regional Foresters of the Intermountain and Northern Regions directed groups of scientists to develop guides for predicting sediment yields and the effect of these sediment yields on fish and their habitats. A standardized method for predicting the effect of sediment yields on stream habitat and fish populations for planning purposes is presented in this report. The method was developed for watersheds and fish species associated with the Idaho Batholith, but the guide has the capability of adaptation to other areas and species with further revision. If used, however, in other areas or for other fish species, the procedure would have to be tested for applicability. Procedures in this report have been coordinated with the "Guide for Predicting Sediment Yields from Forested Watersheds."

Estimation of sediment yield begins on the watershed using the land systems inventory to identify land areas and respective sediment yields. Quantified estimates are made of sediment yields prior to any management, in response to past activities such as fire, roading, logging, and predicting sediment yields for proposed activities. Onsite erosion is modified according to general land unit characteristics and delivered to a stream channel where it is routed to a critical stream reach.

The critical reach(s) is a segment of stream that biologists select to predict changes in fish habitat caused by changes in sediment yield. The biologist then predicts changes in fish embryo survival, summer rearing capacity, and winter carrying capacity from the changes in fish habitat. Finally, the biologist interprets the predicted changes for the land manager.

The fish response modeling of critical reach(s) effects simplifies an extremely complex physical and biological system and is developed from limited scientific knowledge. While it is accepted that an inverse relationship exists between the amount of fine sediments in spawning or rearing areas and fish survival and abundance, the specific fish response curves in this guide were partially developed from laboratory experiments and may constitute only partial simulation of natural conditions.

The user must consider that factors other than sediment may be limiting fisheries production in the streams being evaluated. If, however, sediment is the limiting factor this procedure can appropriately be used to demonstrate "substantial" changes (10-20 percent) in habitat quality and to document the relative differences among planning alternatives. Model outputs are reasonable estimates and not absolute numbers of high statistical precision. Results obtained are to be used in combination with sound biological judgment.

The model outlines a process that can be calibrated locally to better reflect specific conditions. The process was built on state of the art knowledge and experience and will undergo continual change and revision as new information becomes available. The process model will help land managers quantify existing and potential impacts to evaluate trade offs to fish resources from forest management activities. The model also provides methods for assessment of cumulative impacts and fish habitat recovery over time. This further enhances the communication of fisheries issues with Forest decisionmakers, the public, and other agencies interested in fishery management.

The limitations and assumptions about the model are clearly documented because the authors wish to avoid its misuse. The model by itself, will not make decisions nor will it establish standards, objectives, or guidelines. The process is strictly an assessment tool to assist informed decisionmaking. While the model provides an objective and trackable process that can be used to improve the quality of environmental assessments, users should test their model results to be sure they are reasonably accurate.

## INTRODUCTION

The National Forest Management Act (NFMA) of 1976 requires the completion of Forest Management plans by 1985. NFMA regulations specify that alternative management prescriptions be displayed and their effect on various resources and values, including aquatic habitat quality, be identified. As an evaluation tool, the Regional Foresters of the Intermountain and Northern Regions directed groups of scientists to develop guides for predicting sediment yields and the effect of various sediment yields on fish. A standardized method for predicting the effect of sediment yields on stream habitat and fish populations for planning purposes in Idaho is presented in this report.

Procedures and evaluations have been coordinated with the "Guide for Predicting Sediment Yields from Forested Watersheds" (R1-R4 Method) developed by soil and watershed specialists in the Intermountain and Northern Regions (Cline and others 1981). The R1-R4 method provides a procedure for obtaining estimates of average annual sediment yields prior to any development (natural conditions), sediment yields from existing watershed conditions, and sediment yields resulting from proposed management (including roading, logging, and fire). This Guide has been developed for the Idaho Batholith. If used in other areas, the procedure would have to be tested for applicability and recalibrated.

Estimation of sediment yield (Cline and others 1981) begins with onsite erosion on a given land unit, delivery of sediment produced to the stream

channel, and estimates the sediment at a critical stream reach. (See Glossary, Appendix A.) Critical reaches are segments of stream that biologists select to assess the fishery responses from the change in sediment yield. The responses can then be applied to other areas of the stream similar to critical reaches.

An inverse relationship between the amount of fine sediments in spawning or rearing areas versus fish survival and abundance has been found in numerous studies (Bjornn 1969, Cooper 1965, Cordone and Kelly 1961, Hausel and Cobel 1976, Kelley and Dettman 1980, Klamt 1976, McCuddin 1977, McNeil and Ahnell 1964, Phillips and Campbell 1962, Reiser 1981, Stuehrenberg 1975, and Tappel 1982). In general, when sediment yields are increased over natural rates, fish biomass decreases.

A step-by-step approach that relates sediment yields to factors limiting fish abundance is presented in this report. Assumptions that must be made when using these methods are found in Appendix A. The models presented in this report link sediment yield data to fish habitat and population responses. They are based on the best information available. However, this modeling must be recognized as dynamic. There have been previous attempts to build a sediment fisheries model (USDA Forest Service 1977, 1978, and 1979). However, the complex sequence of sediment movement from the slopes to the channel, transport down and deposition in a channel reach, and its effect on fish habitats and populations have not been fully described.

The specific fish response curves (Appendix E) have drawn heavily upon the work of Bjornn (1969), Klamt (1976), McCuddin (1977), and Bjornn and others (1977). These studies were conducted primarily in the laboratory and may constitute only partial simulation of natural conditions. Cederholm and others (1981) found some differences (no statistical significance differences) between laboratory and natural responses in coho salmon embryo survival (Washington). Cederholm also found high variability in measurement of natural situations. However, Kelley and Dettman (1980) found relationships between juvenile summer steelhead (California) and levels of cobble embeddedness in natural streams similar to the responses observed in laboratory studies used in this guide.

When using this guide, the following factors should be understood:

1. The guide was designed primarily for use by fish biologists; however, those with a good biological background will be able to properly apply the system.

2. The guide is most appropriately used to assess the effects of "substantial" changes in habitat quality greater than 10 percent and to document the relative differences between alternatives. Model outputs are reasonable estimates and not absolute numbers of high statistical precision. The results obtained are to be used in combination with sound biological judgment.

3. Sediment yield models should be calibrated for watersheds of the size being analyzed. Application of procedures to uncalibrated watersheds must be conducted with caution (Harr 1980).

## CONCEPTUAL FRAMEWORK

Starting with a problem statement or issue, the fish biologist and interdisciplinary team should identify, in writing, criteria that will be used in evaluating the effects of sediment. Elements of the problem that can be quantified and modeled should also be defined. Examples of criteria are: area affected, type of fish habitat, time period of the analysis, miles of road constructed, and type of timber harvest.

The quantification of fish response to sediment yields is a procedure by which the fish biologist converts the sediment yield data into quantitative fish habitat and population responses. There are major differences between "quantification of fish response" and the "interpretation" of the analysis conveyed to land managers. Professional interpretation is the information the fish biologist gives to the decisionmakers about the fish response to proposed activities.

## CRITERIA

Most criteria significant to fisheries and sediment relationships can be developed in three broad categories: (1) where is the problem, (2) when is the effect, and (3) what activities can influence the area(s) over time?

Where

Ideally two different drainages should not be part of the same problem area. Fish response to sediment yield should be analyzed separately for drainages with different combinations of land allocations or different populations of fish. If no major land disturbing activities were expected, for example in a wilderness area, then it might be logical to group analysis of those areas because no issue or problem with fish response to sediment would be anticipated.

The amount of detail that should be used to break down an individual drainage is a more difficult consideration. Some classic conflicts between timber management and fish production can occur because high value timber is found on highly erodible lands (Platts 1968 and 1972). If this conflict cannot be identified as part of the model, then it is not possible to accurately analyze fisheries response to various land allocations or timber harvest strategies. Modeling spawning areas alone may not be adequate. Consideration should be given to the relative importance of other fish habitat such as winter rearing areas. If riparian areas are to be treated differently than surrounding land, it may be more important to evaluate the effect of the riparian change than that in a particular spawning or rearing area.

## When

In Forest planning, lands are allocated for 10-year periods up to 150-years in the future. Caution should be exercised in interpreting fisheries response over extremely long time periods. Unwarranted assumptions about future mitigation or the objectives of hatchery programs should be avoided. For instance, quality of spawning areas is critical to existing populations of summer chinook salmon in Idaho. Low abundance of spawners of that race of fish in recent years makes high embryo survival necessary for perpetuation of the population; this may not be true in 10 years. It is unlikely that the same considerations would be given to the summer chinook population in 150 years.

## Activities

Activities which should receive primary attention in the sediment/fish analysis are road construction and other land use practices. Sediment production can vary by amount and type of activity, as well as planned mitigation (Cline and others 1981). The R1-R4 model is sensitive enough to portray differences in sediment yield for various activities.

Once criteria are chosen for modeling, the reliability of the modeling system should be validated. The degree to which the model predicts the present conditions based on past activity patterns will determine the credibility of predictions of future responses to proposed land uses.

## FACTORS AFFECTING FISH ABUNDANCE

Fish abundance is limited to some level by various factors, any one of which may be limiting at a particular time. Some examples of limiting factors are:

1. Fry production (Johnson 1965, Argue and others 1979, Bjornn 1978).
2. Rearing space (Chapman and Bjornn 1969).
3. Food (Chapman 1966).
4. Cover (Hunt 1969).
5. Predation (Horner 1978).
6. Temperature (Hann 1977).
7. Harvest (Thurow and Bjornn 1978).

Fish biologists should evaluate all factors and determine if changes in sedimentation will affect the abundance of fish or capacity of the habitat to support fish.

Embryo survival, winter carrying capacity, and summer rearing capacity are related to in-stream sediment and could limit fish abundance. While invertebrate insect abundance (food used by fish) may be directly affected by sediment, the relationship between sediment deposition and invertebrate production is complicated and inconclusive in terms of impacts to fish (Bjornn and others 1977).

Fry production refers to the number of fry which emerge from the gravel. Fry production can be limited by the amount of spawning habitat available, the

seeding rate (number of spawners), or the survival rate from the egg to the emergent stage (Johnson 1965, Argue and others 1979, Bjornn 1978), all of which can be affected by fine sediment.

Juvenile and adult salmonid abundance can be limited by the amount of rearing habitat available (Chapman and Bjornn 1969). Habitat may be segregated into summer areas consisting of pools and runs or over-winter holding areas consisting of interstitial spaces in the channel substrate and deep pools (Bjornn and others 1977, Bustard and Narver 1975, Everest 1969, Chapman 1966, Morrill and Bjornn 1972). In many western streams over-winter habitat could become limited with increases in fine sediment deposition before summer rearing space filled with sediment (Klamt 1976). Fish may move downstream out of some small streams to over-winter (Keating 1958, Reingold 1965, Bjornn 1971), because of low quality winter habitat (Bjornn 1978, Bustard and Narver 1975) in these smaller streams.

## PROCEDURE

To evaluate the effect of sediment on fish in the planning process Forest fish biologists, soil scientists, and hydrologists can use the following step-by-step procedure (Figure 1):

Step 1 - The fish biologist describes the geographical area of concern from a fisheries standpoint, the size of area involved, duration of activities and effects, and the condition (quality and quantity) of existing habitat. The fisheries biologist then evaluates existing data, additional data needs, and assumptions.

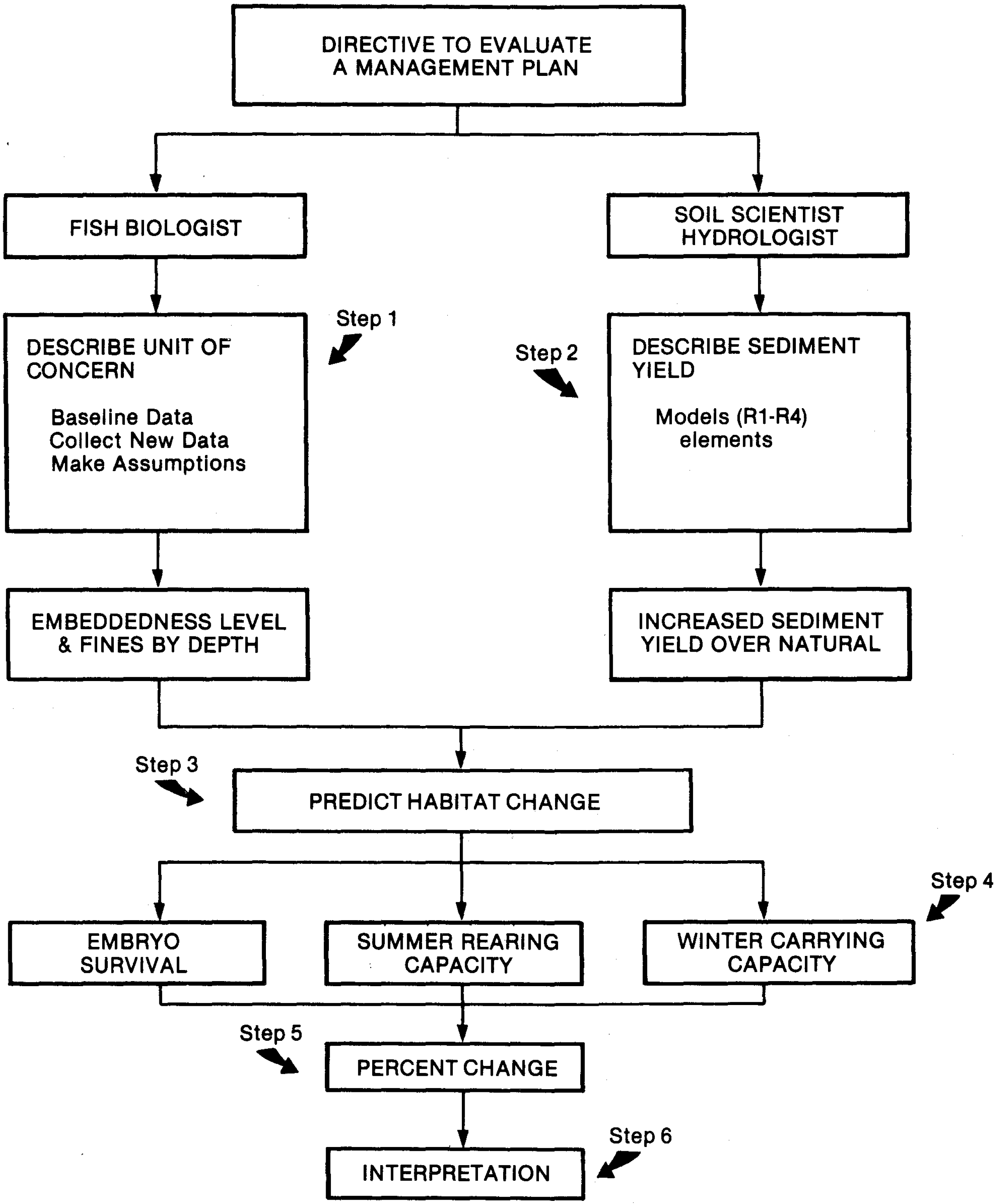


FIGURE 1. Step-by-Step procedure for evaluating the effect of sediment yield on fish habitat and populations.

Step 2 - The soil scientists and hydrologists predict the sediment yield from the area in relation to natural levels using the R1-R4 sediment guide.

Step 3 - The biologist predicts changes in fish habitat (embeddedness and percentage fines of stream substrate) caused by changes in sediment yield using the relationships in Appendix D.

Step 4 and 5 - The biologist then uses the relationships in Appendix E to predict changes in embryo survival, summer rearing capacity, and winter carrying capacity from the changes in fish habitat.

Step 6 - The biologist interprets the predicted changes in fish habitat, embryo survival, and carrying capacity for the land manager.

The process should be used when stream channel sedimentation will result from planned activities and it is believed that such sedimentation will affect fisheries production. The user must consider that factors other than sediment may limit fish production in the streams being evaluated. If the user determines that changes in fine sediment in the stream could be limiting the fish population, then this procedure can be used to help evaluate alternative land uses in the Forest or project planning process.

The following types of data are needed for the application of this guide:

1. Estimates of sediment yield over natural.

2. Substrate core samples from critical channel reaches to determine the existing condition and natural conditions. If core sampling data are not available, estimates can be made from percent surface fines.

3. Measurement of substrate embeddedness in critical reaches to determine the existing and natural conditions. If substrate embeddedness data are not available, estimates can be made from percent surface fines.

4. Stratification of the stream by channel type.

5. Sufficient information on the fish populations to determine if sediment could be significant in limiting abundance and determine the relative importance of spawning, summer rearing, or winter habitat.

The following additional types of data would assist in the interpretation of results:

1. Substrate coring data from several surrounding streams over time.

2. Substrate embeddedness for a majority of the fish production areas.

3. Redd count and/or adult escapement data for key streams over time.

4. Fish density/standing crop data for key streams over time.

5. Classification of the stream by geomorphic and channel type.

6. Stock-recruitment data over time (historical and recent).

7. Empirical relationships between sediment yields and fish habitat.

8. A calibrated watershed model (includes surface and mass erosion components).

## CONCEPTS INVOLVED IN EVALUATION PROCEDURE

To evaluate changes in fish abundance resulting from watershed activities that increase sediment yields, several sediment-fish habitat conceptual relationships must be considered (Figure 2). The natural sediment yield for a watershed is a reflection of geology, climate, and vegetation and varies from year to year. Land disturbing activities such as road construction, timber harvesting, and mining would usually increase sediment yields over the natural rate.

After the watershed disturbances cease, roads and harvest areas begin to stabilize and revegetate. During the watershed recovery period, sediment yields decrease from the previous peak levels during the disturbance to a level near the former natural rate. The new sediment yield rate may be higher than the natural rate because disturbed land areas, such as roads, continue to yield more sediment than did the previous undisturbed areas.

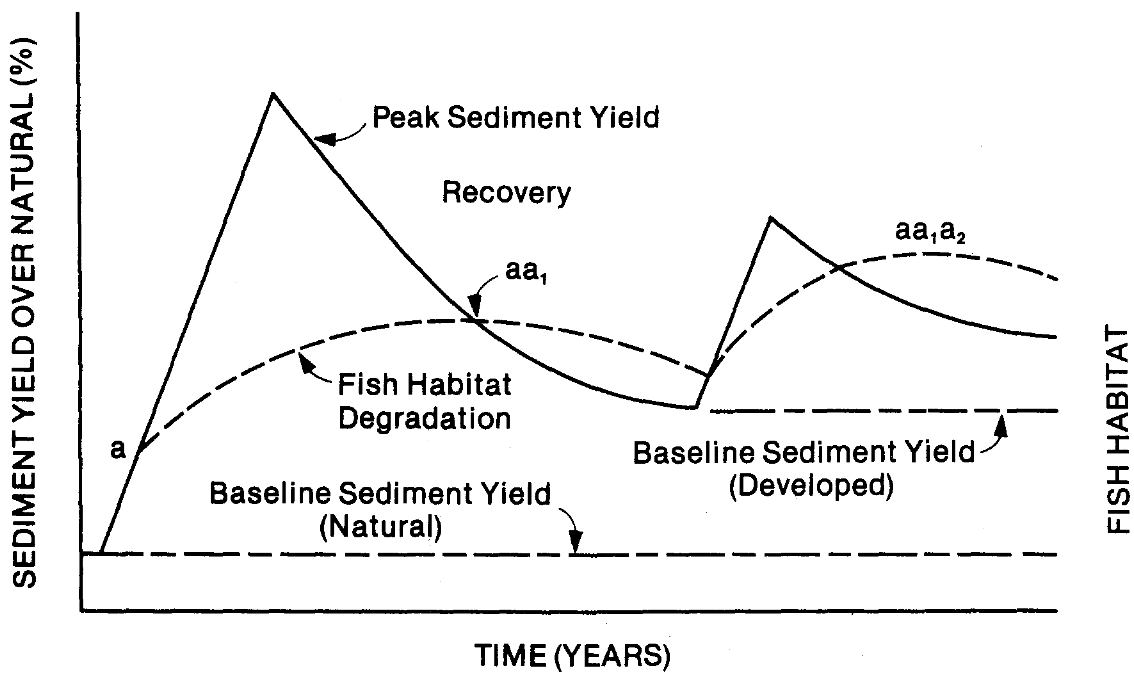


FIGURE 2. Graphic illustration of sediment yields and fish habitat response to sediment producing activities over a short time frame. See text for explanation.

Fish habitat and fish abundance would increase as sediment yield decreases, but at a much slower rate. Additional land disturbing activities in the watershed would again cause similar increases and decreases in the sediment yields with the yields stabilizing at higher rates until the activities cease. Fish habitat (embeddedness or fine sediments) quality would continue to decline and recover in response to the increase or decrease in sediment yields and its resulting stream sedimentation. Fine sediments are those particles less than 6.4 mm in diameter of which at least 20 percent are less than 0.8 mm in diameter.

Effects on channel embeddedness or fine sediment by depth from increases in sediment yield can be illustrated by the general linear regression equation (Figure 3):

$$Y = a + b(X)$$

where Y = Estimated channel embeddedness or fine sediment in channel materials.

a = Natural channel embeddedness or fine sediment by depth.

b = Slope coefficient.

X = Sediment yield over natural as derived using the R1-R4 sediment yield model.

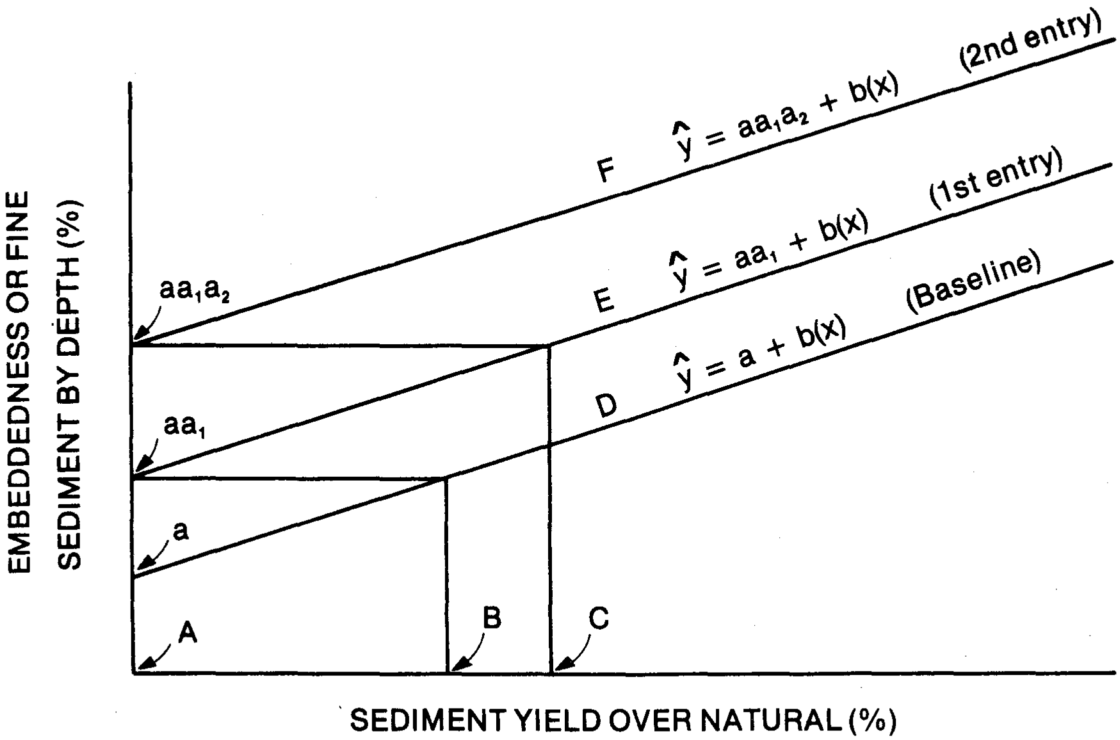


FIGURE 3. Graphic illustration of the cumulative nature of increasing sediment yields on fish habitat parameters over a short time frame, less than 10 years (embeddedness levels and fine sediment by depth).

This represents a hypothetical relationship between sediment yield to the stream and resulting channel embeddedness or fine sediments by depth (fines). The line intercept (point 'a') represents the channel embeddedness or fines by depth under natural conditions. Increases in sediment yields over natural results in an increase in channel embeddedness or fines by depth. For instance, an increase in sediment yield over natural from point 'A' to point 'B' would increase channel embeddedness or fines by depth from point 'a' to point 'aa'.

Since recovery of the habitat is slower than recovery of the watershed, the embeddedness level of fines by depth ('aa') becomes the new habitat condition (Line 'E', Figure 3) and the predictive equation changes to:

$$Y = aa + bX$$

but aa = channel embeddedness or fines by depth at the newly stabilized level following some watershed disturbance.

and X = sediment yield over the natural rate for first activity period.

Cumulative effects of repeated sediment yield increases on fish habitat can be estimated if the estimated sediment yields from the first or subsequent entries do contain significant residual sediment yields. If sufficient time is allowed for recovery back to the baseline condition, then the impact can be estimated from the original equation, $Y = a + bX$.

The two examples (step-by-step procedures) presented in this guide are based on the relationships developed from data collected on streams in the Clearwater and Nezperce National Forests, Idaho (Appendix D). These relationships significantly correlate empirical data on channel embeddedness and percent fines by depth in stream substrates with sediment yields as predicted by the R1-R4 model (Appendix F). Linear models of the relationships are used as the predictive equations. Cederholm and others (1981) working in 43 coastal tributaries of the Olympic Peninsula Basin (Washington) have established a significant (1 percent level) and similar linear relationship between watershed disturbance (roads) and sedimentation (percent fines) in downstream spawning gravels.

Sediment transport capabilities depend on channel factors such as gradient, stream flow, bed roughness, and sinuosity. For purposes of this guide, stream channels have been classified into three broad types (A, B, and C, Appendix C) (Collotzi 1974, and Espinosa and others 1981, Rosgen and Silvey 1980). Critical reaches must be classified as one of the channel types for interpretive purposes.

Streams in the Clearwater and Nezperce National Forests with natural sediment yields had substrate embeddedness ratings of 15 to 25 percent and percentage fine sediments by depth of about 15 to 20 percent (Appendix D). Streams in other drainages may have higher or lower base levels of fine sediment in channel substrates under natural sediment yields. Streams also

differ in their ability to transport increased sediment yields. In some streams, channel embeddedness and fines in the substrate may not change until

there are substantial increases in sediment yield (Cederholm and others 1981). For example, sediment yields would have to increase to more than 100 percent over natural in A type (steep gradient) channels before significant changes in substrate embeddedness would occur in these streams on the Clearwater National Forest. According to the data in Appendix D, with sediment yields to 100 percent over natural in A type channels, 45 percent in B, and 35 percent in C type channels (see Appendix C for channel classifications), insignificant changes in substrate embeddedness would occur in streams of the Clearwater National Forest. The sediment yield over the natural rate that could occur before substantial changes in habitat quality would take place (threshold effect) should be determined for the individual channel types of each Forest.

We believe it appropriate to issue a caution about the utilization of channel types to stratify fish response. These reasons are:

1. Average deposition in high gradient streams (A type channels) may not realistically represent deposition in fish habitat. Work by the USDI-FWS Instream Flow Group shows that salmonids occupy relatively narrow ranges of water velocity, depth, and substrate (Bovee and Cochnauer 1978). These "micro-hydraulic" habitats may well be subjected to similar deposition regardless of gross channel morphology. Furthermore, in high gradient streams, the low velocity, low energy sites occupied by fish might be subject to relatively more deposition than lower gradient streams with identical absolute quantities of sedimentation. The channels described as "B" and "C" type channels should contain relatively more fish habitat than "A" type channels. Based on this we would expect data from "B" and "C" type channels

to more accurately represent impacts to fish habitat regardless of gross channel morphology.

2. The efficiency of the type "A" channel with regard to sediment transport may lead to a potential problem of sediment concentration in downstream channels with less gradient. This is a common problem in areas such as the South Fork of the Salmon River.

3. The landtypes which "A" channels drain are typically steep canyon lands. These areas are the highest hazard lands with regard to sediment production. Doubling sediment production from these landtypes could have a larger impact downstream than analysis of only a type "A" drainage would indicate. If type "A" drainages are developed, downstream cumulative impacts in more sensitive reaches also need analysis.

## EXAMPLES OF USE

The following examples have been provided to aid in understanding the step-by-step procedures. Example 1 consists of a watershed in natural condition where multiple land disturbing entries (two) are planned for a particular management activity. Example 2 consists of an already developed watershed where a single entry is planned for a particular management activity.

Example 1

Step 1: Describe Unit of Concern.

The watershed is in natural condition and contains a steelhead trout population at carrying capacity. The critical reach is a C-channel type. Channel substrate embeddedness and fines by depth are 25.2 percent and 18.5 percent, respectively.

Step 2: Determine Sediment Yield.

Based on the proposed management activities, the R1-R4 model predicts an increase of 70 percent over natural sediment yields for the first entry, and an additional 32 percent for the second entry. The second entry closely follows the first entry allowing no watershed or habitat recovery.

Step 3: Predict Habitat Changes.

Using the procedures in this guide and the R1-R4 sediment yield output, predict channel substrate embeddedness and fines by depth that will result from the changes in sediment yield.

A. Substrate Embeddedness - Predict embeddedness for the first ($Y_1$) and second ($Y_2$) entry based on predicted increases over natural (70 percent and 32 percent) (Appendix D, Figure D-3 and Appendix F, Equation C).

$$Y_1 = 25.2 + 0.16(70) = \underline{\underline{36.4\%}} \text{ embeddedness}$$

$$Y_2 = \underline{\underline{36.4}} + 0.16(32) = 41.5\% \text{ embeddedness}$$

also:

$$Y_2 = 25.2 + 0.16(70 + 32) = 41.5\% \text{ embeddedness}$$

B. Fines by Depth - Predict fines by depth for the first ($Y_1$) and second ($Y_2$) entry based on predicted increases over natural (70 percent and 32 percent) (Appendix D, Figure D-4 and Appendix F, Equation D).

$$Y_1 = 18.5 + 0.12(70) = \underline{\underline{26.9\%}}$$

$$Y_2 = \underline{\underline{26.9}} + 0.12(32) = 30.7\%$$

## Step 4: Predict Fish Population Changes.

Using the fish habitat results calculated above and the relationships in Appendix E, estimate existing and predicted embryo survival, summer rearing capacity, and winter carrying capacity.

A. Embryo Survival - Estimate the existing ($Y_{e1}$, $Y_{e2}$) and predicted ($Y_{p1}$, $Y_{p2}$) embryo survival for the first and second entry based on the existing (18.5 percent) and predicted (26.9 and 30.7 percent) fines by depth (Appendix E, Figure E-1 and Appendix F, Equation E).

$$Y_{e1} = 80.73/1 + e^{\left[(-9.525) + (.3677) \times (18.5)\right]} = 75.8\%$$
$$Y_{p1} = 80.73/1 + e^{\left[(-9.525) + (.3677) \times (26.9)\right]} = 33.1\%$$
$$Y_{e2} = 80.73/1 + e^{\left[(-9.525) + (.3677) \times (26.9)\right]} = 33.1\%$$
$$Y_{p2} = 80.73/1 + e^{\left[(-9.525) + (.3677) \times (30.7)\right]} = 11.8\%$$

Note: The predicted fines by depth for entry 1 (26.9) becomes the existing fines by depth for entry 2 if the sediment yield remains at 70 percent.

B. Summer Rearing Capacity - Estimate the existing ($Y_{e1}$, $Y_{e2}$) and predicted ($Y_{p1}$, $Y_{p2}$) summer rearing capacity for the first and second entry based on the existing (25 percent) and predicted (36.2 percent and 41.3 percent) substrate embeddedness (Appendix E, Figure E-3(A) and Appendix F, Equation G).

$$Y_{e1} = 100 + 0.016(25.0) - 0.007(25.0)^2 = 96.0\%$$
$$Y_{p1} = 100 + 0.016(36.4) - 0.007(36.4)^2 = 91.3\%$$
$$Y_{e2} = 100 + 0.016(36.4) - 0.007(36.4)^2 = 91.3\%$$
$$Y_{p2} = 100 + 0.016(41.5) - 0.007(41.5)^2 = 88.6\%$$

C. Winter Carrying Capacity - Estimate the existing ($Y_{e1}$, $Y_{e2}$) and predicted ($Y_{p1}$, $Y_{p2}$) winter carrying capacity for the first and second entry based on existing (25 percent) and predicted (36.4 percent and 41.5 percent) substrate embeddedness (Appendix E, Figure E-4(B) and Appendix F, Equation K).

$$Y_{e1} = 100e^{-0.026(25.0)} = 52.2\%$$

$$Y_{p1} = 100e^{-0.026(36.2)} = 39.0\%$$

$$Y_{e2} = 100e^{-0.026(36.2)} = 39.0\%$$

$$Y_{p2} = 100e^{-0.026(41.3)} = 34.2\%$$

Step 5: Interpret the Predicted Changes.

From the percentage changes between the existing and predicted values for cobble embeddedness, fines by depth, embryo survival, summer rearing capacity, and winter carrying capacity, the fish biologist must interpret the significance of such changes for the fish populations in question. This may require adjustment of the response curve's outputs to reflect individual variation in natural (pristine) conditions of the habitat as it may vary from drainage to drainage (i.e. 25 percent cobble embeddedness and 52.2 percent of winter capacity may be equivalent to 100 percent of winter carrying capacity in that drainage, see item C above). It is recommended that all predicted changes be rounded to the nearest whole number due to the precision of the model.

A. Substrate Embeddedness - Substrate embeddedness increases from an existing 25.0 percent (pristine condition) to 36.4 percent with the first entry and 41.5 percent increase with the second entry; a 65 percent increase in embeddedness

$$\frac{(41.5 - 25.0)}{25}(100) = 65\%.$$

B. Fines by Depth - Fines by depth increased from an existing 18.5 percent (pristine condition) to 26.9 percent with the first entry and 30.7 percent with the second entry; a 53 percent increase in fines.

C. Embryo Survival - Embryo survival decreased from an existing 75.8 percent to 33.1 percent with the first entry and 11.8 percent with the second entry; a 84 percent reduction in embryo survival.

D. Summer Rearing Capacity - Summer rearing capacity decreased from an existing 96.0 percent to 91.4 percent with the first entry and 88.6 percent with the second entry; an 8 percent reduction in capacity.

E. Winter Carrying Capacity - Winter carrying capacity decreased from an existing 52.2 percent to 39.0 percent with the first entry and 34.2 percent with the second entry; a 34 percent reduction in capacity.

The biologist must use all the available information and professional judgment to determine to what extent changes in embryo survival, summer rearing capacity, or winter carrying capacity are likely to limit fish abundance.

Example 2

Step 1: Describe Unit of Concern.

The watershed in the Idaho Batholith is already developed and contains a steelhead trout population at carrying capacity for existing conditions. The critical stream reach is a B-channel type. Existing substrate embeddedness and fines by depth are 50 percent and 30 percent, respectively.

Step 2: Predicted Sediment Yields.

Based on the proposed management activity, the R1-R4 sediment yield model predicts an increase of 70 percent over natural sediment levels. This includes the existing sediment yield over natural and the proposed management activity.

Step 3: Predict Habitat Changes.

Using this guide and the R1-R4 sediment yield output, predict substrate embeddedness and fines by depth.

A. Substrate Embeddedness - Predict new substrate embeddedness (Appendix D, Figure D-2 and Appendix F, modified Equation B).

$$Y = 50.0 + 0.09(70) = 56.3\%$$

B. Fines by Depth - Predict new fines by depth (Appendix D, Figure D-4 and Appendix F, modified Equation D).

$$Y = 30.0 + 0.12(70) = 38.4\%$$

Step 4: Predict Fish Population Changes.

Using fish habitat results calculated previously and relationships that appear in Appendix E, estimate existing and predicted embryo survival, summer rearing capacity, and winter carrying capacity.

A. Embryo Survival - Using the existing (30.0 percent) and predicted (38.4 percent) fines by depth estimate the existing ($Y_e$) and predicted ($Y_p$) embryo survival (Appendix E, Figure E-1 and Appendix F, Equation E).

$$Y_e = 80.73/1 + e^{(-9.525) + (.3677) \times (.30)} = 14.7\%$$

$$Y_p = 80.73/1 + e^{(-9.525) + (.3677) \times (38.4)} = 1\%$$

B. Summer Rearing Capacity - Using existing (50.0 percent) and predicted (56.3 percent) cobble embeddedness estimate the existing ($Y_e$) and predicted ($Y_p$) summer rearing capacity (Appendix E, Figure E-3(A) and Appendix F, Equation G).

$$Y_e = 100 + 0.016(50.0) - 0.007(50.0)^2 = 83.3\%$$

$$Y_p = 100 + 0.016(56.3) - 0.007(56.3)^2 = 78.7\%$$

C. Winter Carry Capacity - Using existing (50.0 percent) and predicted (56.3 percent) cobble embeddedness estimate the existing ($Y_e$) and predicted ($Y_p$) winter carrying capacity (Appendix E, Figure E-4(B) and Appendix F, Equation K).

$$Y_e = 100e-0.026(50.0) = 27.3\%$$

$$Y_p = 100_e-0.026(56.3) = 23.1\%$$

Step 5: Interpret the Predicted Changes.

From the percentage change between the existing and predicted values for substrate embeddedness, fines by depth, embryo survival, summer rearing capacity, and winter carrying capacity, the fish biologist must interpret the significance of such changes for the fish populations in question.

A. Substrate Embeddedness - Substrate embeddedness increased from 50.0 percent to 56.3 percent; a 13.0 percent increase.

B. Fines by Depth - Fines by depth increased from 30.0 percent to 38.4 percent; a 28.0 percent increase.

C. Embryo Survival - Embryo survival decreased from 14.7 percent to 1 percent; a 78.7 percent decrease in survival.

D. Summer Rearing Capacity - Summer rearing capacity decreased from 83.3 percent to 78.7 percent; a 6.0 percent decrease.

E. Winter Carrying Capacity - Winter carrying capacity decreased from 27.3 percent to 23.1 percent; a 15.0 percent decrease.

## Summary

The biologist must use information available and professional judgment to interpret the percentage changes in embryo survival, summer rearing capacity, and winter carrying capacity. An additional example using a different approach (stock-recruitment data) is presented in Appendix G to illustrate that there are other methods to evaluate sediment-fish responses if the necessary data are available.

## EVALUATING HABITAT RECOVERY

Recovery of fish habitat over time should be incorporated into the analysis as a function of watershed recovery and responding stream habitat recovery because long-term effects often overshadow the short-term effects. Seldom is this type of recovery data or experience available. The only data available to demonstrate fish habitat recovery, after receiving large amounts of accelerated sediment, are from the South Fork Salmon River (SFSR). There are few stream reaches directly comparable to the SFSR so its recovery rate can only be used as an example of how a stream the size of the SFSR, under the type of logging and road construction that occurred, reacted to the climatic conditions during the period of recovery.

Recovery of fish habitat in this river has been measured over an 18-year period. Recovery for the SFSR should not be used in developing recovery rates for other batholith streams, because no testing has been done to determine if its reaction can be extrapolated to other drainages. It's doubtful if any

other stream in the batholith would react identically to the SFSR but it's possible that many streams may react similarly. If so, it would be a matter of attempting to match a sensible recovery to the stream in question. The user is going to have to use his best judgment as habitat recovery is too important to completely ignore in the analysis.

## South Fork Salmon River Example

### History

The SFSR historically (1950's) contained Idaho's largest salmon run, and great concern was expressed when increases in fine sediment were observed in chinook salmon habitat. These conditions were caused primarily by logging and road construction from 1950 through the mid 1960's on lands of high erosion hazard. By 1965, 15 percent of the lands within the upper half of the watershed had been included in logging sale boundaries (Platts and Megahan 1975). In addition, 622 miles of roads had been constructed, mostly in conjunction with timber sales. Storms in 1962, 1964, and 1965 on the newly disturbed lands accelerated soil erosion, particularly on logging roads (Megahan and Kidd 1972). The course texture (mostly coarse sands) of the soil material and the large amounts eroded from the watershed altered the size composition of the river substrate. The USDA Forest Service declared a moratorium on logging and road construction and initiated a watershed rehabilitation program in 1965.

## Methods and Available Data

Methods and the data used to determine time trends in the river channel surface and subsurface sediment composition are described in Corley and Newberry 1983, Platts and others 1983, Megahan and others 1980, and Platts and Megahan 1975.

## Interpretation of Recovery

From about 1950 to 1965, a deteriorating situation existed in fish habitat in the river because of accelerated erosion from expanding logging and road construction. This resulted in a sediment yield at a rate higher than the river could transport and remove from its system (Figure 4). After 1965, sediment supplied to the river was reduced through natural and management rehabilitation changes, and the river was able to start cleansing itself as the transport capacity of the river again exceeded the sediment supplied from the watershed.

Because of the present road systems and disturbed lands remaining in the South Fork Salmon River drainage, and based on the work of Megahan and Kidd (1972) on accelerated soil erosion rates on disturbed lands over time, it is understandable why the SFSR would not return to a natural condition during the 18 year recovery period. The river has stopped its initial rapid recovery probably because the annual accelerated and natural sediments entering the system keep the river from cleansing further at a detectable rate.

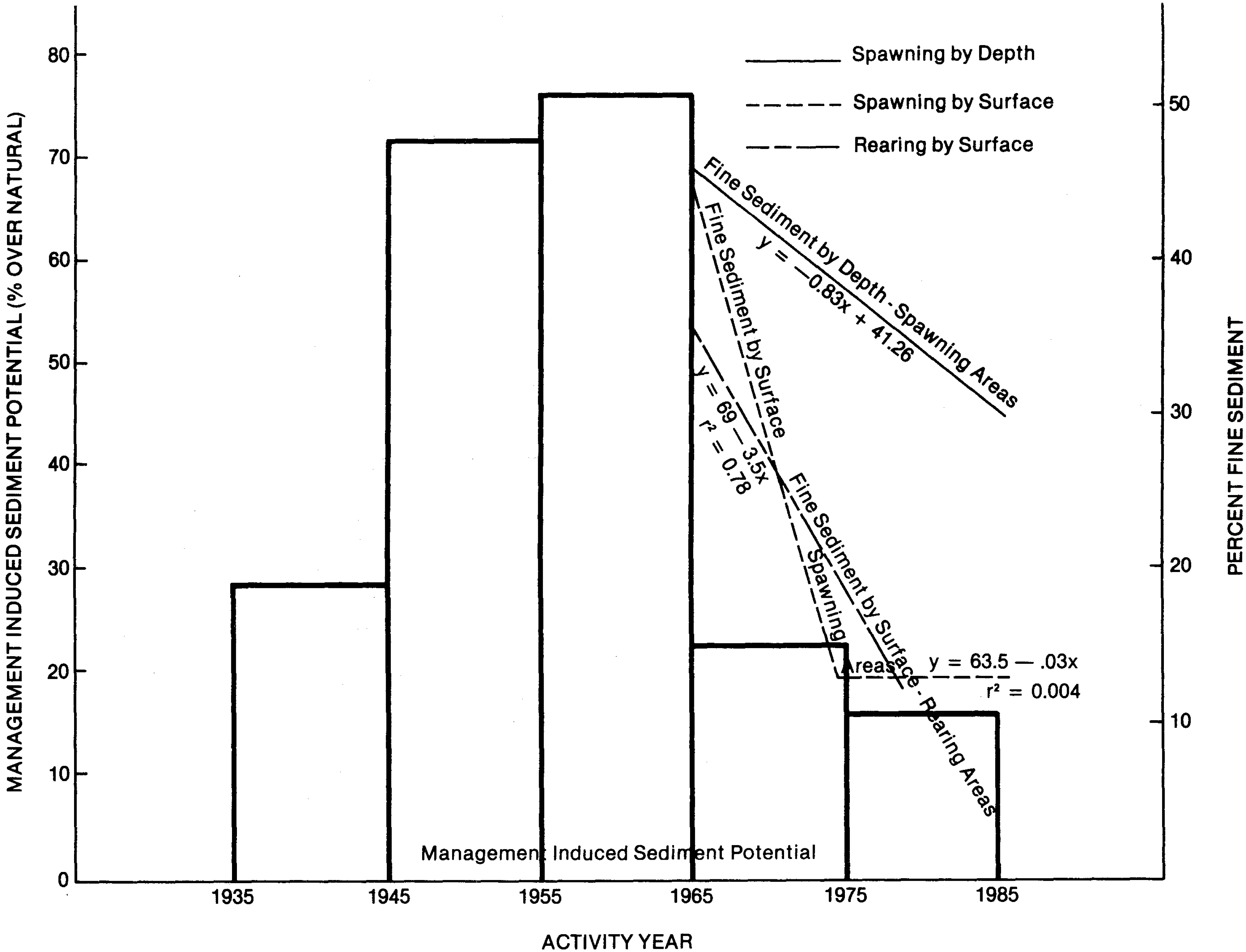


FIGURE 4. A comparison of accelerated sediment being received by the South Fork Salmon River and its channel surface and depth reaction to it (Sediment potential from John and Kulesza 1982).

Fish habitat recovery to full potential is not likely in heavily disturbed watersheds such as in the SFSR drainage because permanent roads and even roads closed and rehabilitated will continue to produce sediment at levels higher than undisturbed slopes (Megahan 1974, Megahan and Kidd 1972).

## South Fork Salmon River Recovery Rates By Channel Surface Analysis in Spawning Areas

The percentage of the total SFSR channel surface occupied by each fine sediment size class in the SFSR spawning areas declined from 1965 to 1982 (Figure 4). The statistical significance of the trend was tested by fitting a linear regression to the data by stratifying the time span into two separate time periods 1966 to 1974 and 1975 to 1982. This was done to display the faster recovery rate in the initial period of recovery and a second period where little surface recovery occurred.

Fine sediments made up 45 percent of the surface materials in 1965 (Figure 4). Nine years later (1974), only 13 percent, but 18 years later (1983), it was still 13 percent. Full recovery of the SFSR spawing areas (surface fine sediments) is estimated to be 8 percent[1/] surface fine

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[1/] Platts, W. S. (personal communication 1983) estimates that naturally the SFSR channel surface materials in the major salmon spawning areas averaged about 8 percent fine sediments and channel sediments by depth (to 30.5 cm) averaged about 25 percent.

sediments. Thus, it had to reduce its surface fine sediment composition by 37 percentage points for total recovery; however, in 9 years it dropped to 14 percent for an overall recovery of 84 percent of surface habitat potential, or an average of about 9 percent per year. The SFSR presently has 16 percent of its recovery to complete, and the river is finding the last part very difficult to accomplish; therefore, this 16 percent must be considered as that part of the recovery the SFSR cannot gain in a normal planning future (5 to 10 years).

Recovery of spawning area surface habitat started in 1965 (after the last major land disturbance) in the SFSR. For the user to consider using the SFSR transport and recovery rates as an example to use in a prediction of a stream's recovery rate, one must consider the exact conditions that occurred (climatic storms, logging and road building moratorium, road closures, and a road rehabilitation program) in the SFSR in comparison to the stream that is being analyzed. These conditions will never be met exactly; therefore, the user must interpret his situation accordingly. Full recovery of fish habitat in the SFSR has not occurred in 18 years and may not ever occur.

## By Channel Surface Analysis in Rearing Areas

Surface fines in rearing areas were determined in 1967, 1971, 1972, 1973, 1974, and 1977 (Figure 4). The decrease in fine sediments in the channel followed much the same pattern as that found in the spawning areas. In 1966 rearing areas had 35 percent fine sediment compared to 45 percent in spawning areas, and by 1977 they were both about 14 percent. The decrease for fine

sediment for both was statistically significant at the 90 percent confidence level.

Surface fine sediments in rearing areas were 36 percent in 1965, 12% in 1978, and based on spawning surface analysis about 12 percent in 1982. This is approximately a 6 percent recovery rate per year. The recovery rate was probably slightly higher during the early time periods, but we do not have enough data to identify the relationships. We also lack the information to accurately determine the recovery yet to be gained but Platts (see footnote 1) assumed that the river rearing areas naturally contained 6 percent surface fines based on personal observations. The river then still has 20 percent of its potential recovery to gain.

The user must keep in mind that the reduction of surface fines in fish habitat may not accurately portray recovery in spawning habitat but may indicate trends towards recovery of summer and winter rearing habitats. The user should analyze the subsurface fines to properly evaluate spawning area recovery. If the biologist only has surface sediment data, then it may be appropriate to use a ratio expressing the relationship between surface and depth recovery rates as depicted in the SFSR, (i.e., 6 percent year depth ÷ 8 percent year surface equals 0.75X where X equals the surface recovery rate.

By Channel Subsurface (Spawning Area) Analysis

The general downward trend in fine sediments in all spawning areas was statistically significant at the 95 percent confidence level (Figure 5). Fine sediments decreased from a high of 40 percent to 45 percent to 31 percent of the substrate by 1982. Reduction of fines in spawning areas by depth was slower than the reduction in elevation of surface fines. Depth materials probably contained more fine sediments naturally than appeared on the channel.

From 1966 through 1973, in the Poverty spawning area, fine sediments <6.35 mm in particle size accounted for about 40 percent to 45 percent of the total spawning substrate with little change being observed during the 9-year period. In 1975 the Poverty spawning area averaged about 37 percent fine sediments and by 1982 it was 31 percent. Similar trends were found for sediments <0.8 mm in particle size that dropped from 16 percent in 1966 to 12 percent in 1979 to 10 percent in 1982. Platts (see footnote 1) assumed that under natural conditions in the SFSR Poverty spawning area contained about 25 percent fine sediments (<6.35mm).

Both surface and subsurface sand decreased significantly over time, but surface sands decreased at a greater rate. Less energy is required to remove sand from the bed surface than is required to remove sand mixed with gravels and rubble within the bed (Morisawa 1968).

The Poverty spawning area recovered very little the first 10 years and then fine sediments were reduced 50 percent in the next 7 years (about 7 percent per year). Even with the delayed reaction it is estimated by Platts

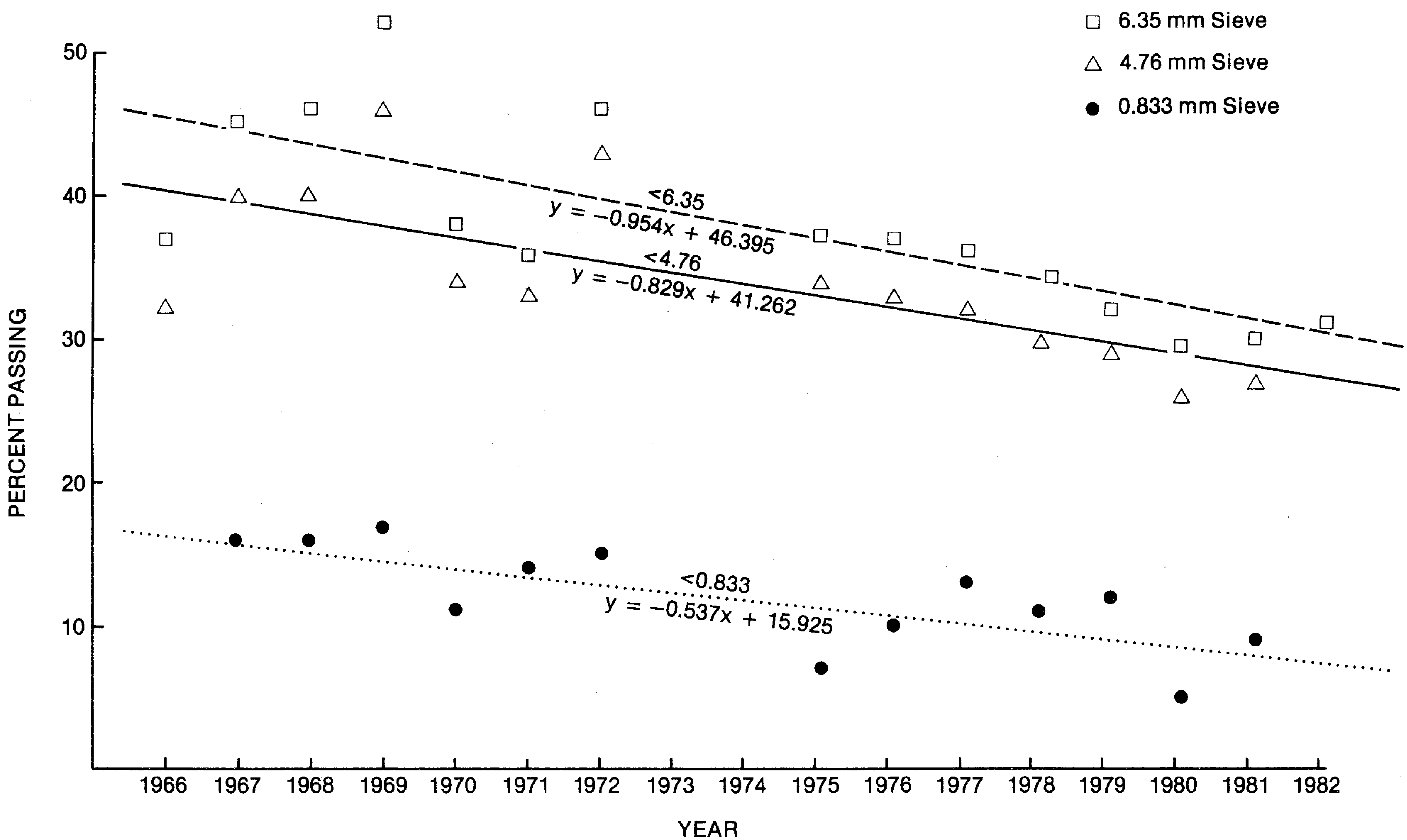


FIGURE 5. Time trend in percent of fine sediments of selected sizes beneath the surface of the Poverty spawning area. (Data from Corley, 1982; Torquemada and Platts, 1983.)

(see footnote 1) that the remaining potential level of recovery rate unattainable is 30 percent.

## SUMMARY

We realize the predicament that users of this guide are in, trying to determine recovery rates of impacted streams. At this stage of research on spawning area recovery, information is sparse. The SFSR is the only fishery stream in Idaho that has sound recovery data and this river may be unique enough that information cannot be extrapolated easily. Habitat recovery rates must be considered when predicting the effects of logging and road construction, so the users may have to use their judgment incorporating factors such as the SFSR example as well as local information.

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# APPENDIX

# APPENDIX A

## Assumptions

Assumptions

1. Sediment delivery to and deposition in stream channels is an important source of mortality to salmonids. Other variables such as temperature, oxygen, and stream flow are not within the scope of this guide.

2. Each Forest in the Northern and Intermountain Regions will use the R1-R4 guide for predicting sediment yields. Estimates of relative sediment yields (both natural and management induced) derived from this guide are "reasonably" accurate.

3. On those Forests in which mass erosion is a significant hazard, predicted sediment yields will include a mass erosion component.

4. As long as sediment inputs to the channels exceed transport capacities, impacts to fish habitat are cumulative.

5. The relative response of salmonid fish populations to increased levels of sediment and percent fines in the substrate as depicted in laboratory (flume) studies approximates the response under natural conditions.

6. Degraded fish habitats and populations usually recover at slower rates than their watersheds (Megahan and others 1980).

7. Methodologies described can be used at the Forest level of planning with a limited data base and at the project level with an intensive data base.

8. Critical channel reaches within each watershed can be used to estimate effects on the entire stream. Several reaches may be necessary to adequately represent a diverse watershed.

9. Fish populations characterized by low levels of adult spawning escapement (under-seeded habitat) are regulated at the spawning-reproductive phase of their life history.

10. Fish populations characterized by high levels of adult spawning escapement (fully-seeded habitat) are regulated at the rearing phase of their life history.

11. Variations in spawning escapement and natural climatic events may mask changes in fish production due to habitat conditions.

## APPENDIX B

### Glossary

Anadromous - Fish such as salmon and steelhead trout that spawn and rear their young in fresh water which then migrate to the ocean to mature.

Alevin - Stage in the fish life cycle after the hatching stage to emergence from the gravel.

Fish Biomass - Weight of fish per unit of stream surface area (fish/$m^2$).

Critical Stream Reaches - Reaches of a stream that will reflect changes in fish habitat from sediment yields from a specific area of interest and that are representative of given sections of the stream.

Depth (subsurface) Fines - Portion of the channel materials from the channel surface to a vertical depth of 8 inches that is composed of fine sediments.

Embeddedness - A rating of the degree the larger particle sizes (e.g., gravel, rubble, and boulder) are covered with fine sediments. A zero rating means the particles are free and clear of fine sediments and their entire perimeter is available for direct contact with the water except for that part touching other particles other than fine sediment. A 100 percent rating would occur when the particle is completely covered by fine sediments.

Fine Sediment - Particles in the channel that are less than 6.4 mm in diameter.

Juvenile - Stage in the life cycle of a fish after hatching to the adult stage.

Natural Sediment Yield - Quantity of particles derived mainly from streambank erosion or material supplied by creep and other mass erosion processes inherent to the area. Under natural conditions surface erosion is assumed negligible (USDA Forest Service 1981).

Pool Volume - Amount of water a pool contains at a selected flow.

Percent Fines - Percentage of the substrate composed of particles smaller than a selected diameter.

Rearing Area - Area of the stream occupied by fish after they emerge from the gravel.

Resident - Fish that live in the area year around; they do not migrate to the ocean as part of their life cycle.

Sediment Yield - Quantity of sediment ($tons/mi^2/yr$) produced from the watershed upstream from a given stream section.

Smolt - That stage of an anadromous fish's life cycle when they undergo certain morphological change just prior to or during their descent from the rearing areas to the ocean.

Surface Fines - Those particles on the channel surface smaller than a selected diameter.

Winter Habitat - Area of the stream occupied by fish during the winter. This could be deep pools, rubble-boulder riffles, or warmer water area. In this report, it refers mainly to the rubble-boulder riffle areas that juvenile salmonids enter to survive winter conditions.

# APPENDIX C

## Channel Classifications

## Channel Classifications

### Type A

These channels generally drain the following landforms: breaklands, mass wasted lands, colluvial drift slopes, and frost churned uplands. The adjacent landforms are steep with heavy, coarse alluvium or colluvium. The channels are generally contained within narrow valley bottoms with steep slopes or walls (>50 percent) on either side. The channel form is well-incised and "v"-shaped with annual peak flows contained. Stream gradient over the reach is normally greater than or equal to 6 percent. Stream order is usually 1-3. The streambed is characterized by bedrock, large rubble, and boulders with a high degree of armoring and low detachment. Major habitat-types are dominated by riffles, runs, and pocket water. Pools are formed by large boulders, bedrock outcrops, and large organic debris. Sinuosity ratio equals 1.0 to 1.1. Sediment supply (natural) is generally low depending upon the adjoining landforms. Sediment delivery is rapid and efficient.

### Type B

These channels generally drain the fluvial dissected slopelands, high alluvial terraces, some colluvial drift slopes, mini-breaklands, and old erosional surfaces. The adjacent landforms have slopes that range from 0 to 50 percent gradients. Stream gradients over the reach vary between 3 and 6 percent. Channel form is moderately incised, broad "v"-shaped with annual peak flows generally contained. Stream order is normally 1-4. The streambed is characterized by small to large boulders, small to large rubble, and coarse

gravel with some fine gravel, sand or silt. The substrate is moderately armored with moderate detachment. The habitat-type profile is dominated by pools, riffles, and pocket water. Pools are formed by large organic debris, meanders, and bedrock outcrops. Sinuosity ratio ranges from 1.1 to 1.3. Sediment supply (natural) is generally moderate with a wide variation in delivery efficiency (low to high) depending upon contiguous landforms.

Type C

Type C channels are generally located in moderately wide to very wide valley bottoms. Valley slopes vary considerably, ranging from old erosional surfaces to low relief glaciated uplands. Adjacent landforms are generally low in gradient, containing fine-textured residual soils; however, C channels may also typify high elevation glaciated troughs and breaklands. Stream gradient over the reach is normally less than or equal to 3 percent. Channel entrenchment is shallow with frequent overbank discharge. The streambed is characterized by large amounts of large and small rubble, coarse and fine gravels with lesser amounts of small rubble, coarse and fine gravels with lesser amounts of small boulders, sand, and silt. Streambed has little or no armoring with easy detachment. Sinuosity ratio varies from 1.5 to 2.0+. The habitat-type profile is characterized by heterogeneity. High quality pools and runs are more dominant in this channel type. Pools are formed by large organic debris and meanders. Extensive areas of spawning habitat are frequently found in this channel type. Sediment supply is relatively high; however, delivery efficiency from adjoining slopes is low. Streams characterized by a C channel profile are generally considered to provide the highest quality spawning and rearing habitats for salmonids.

# APPENDIX D

## Sediment-Habitat Response Curves

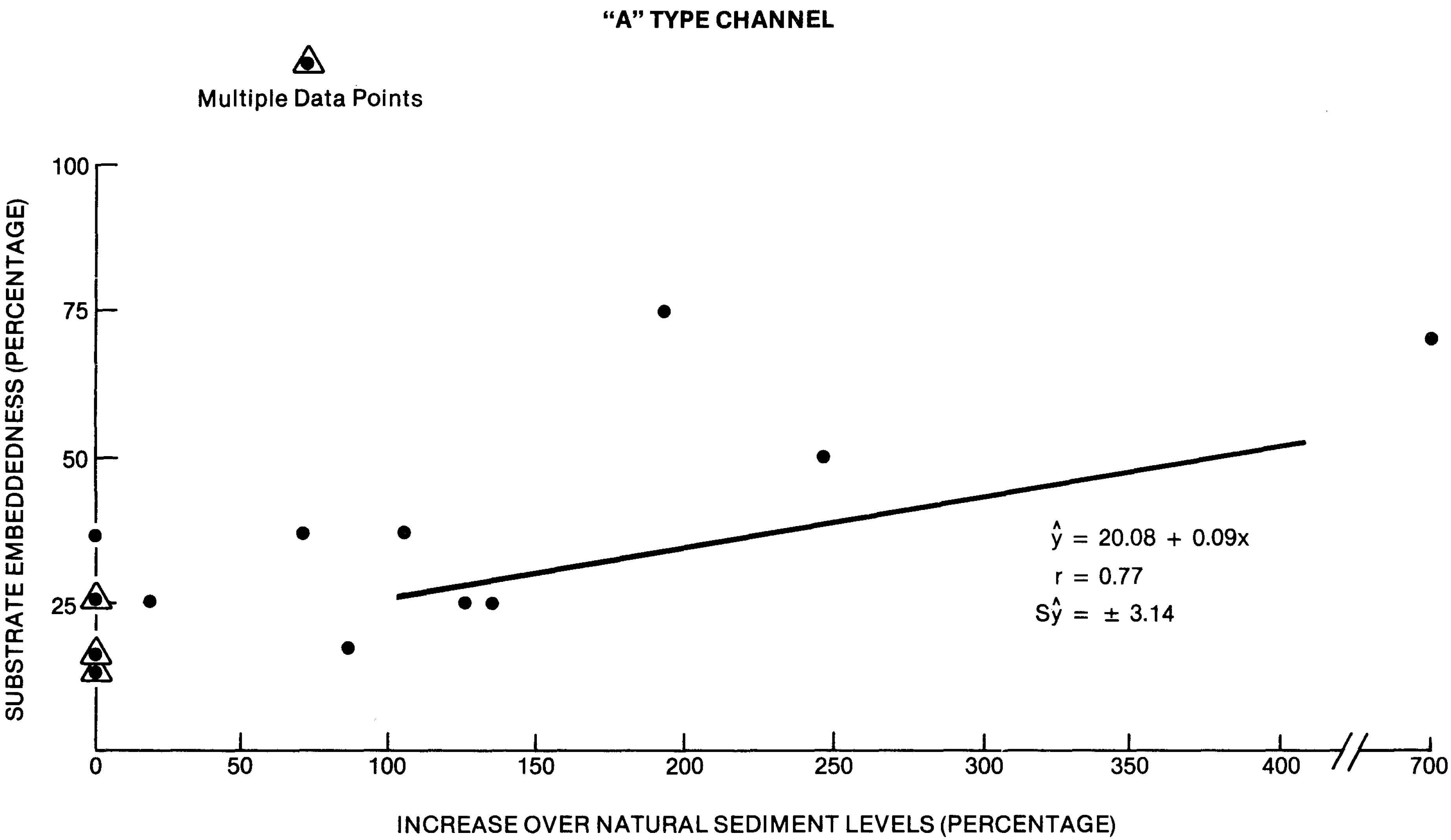



FIGURE D-1. Substrate embeddedness of streams with "A" type channels in the Clearwater and Nez Perce National Forests versus estimates of sediment yield (R1-R4 model).

**"B" TYPE CHANNEL**

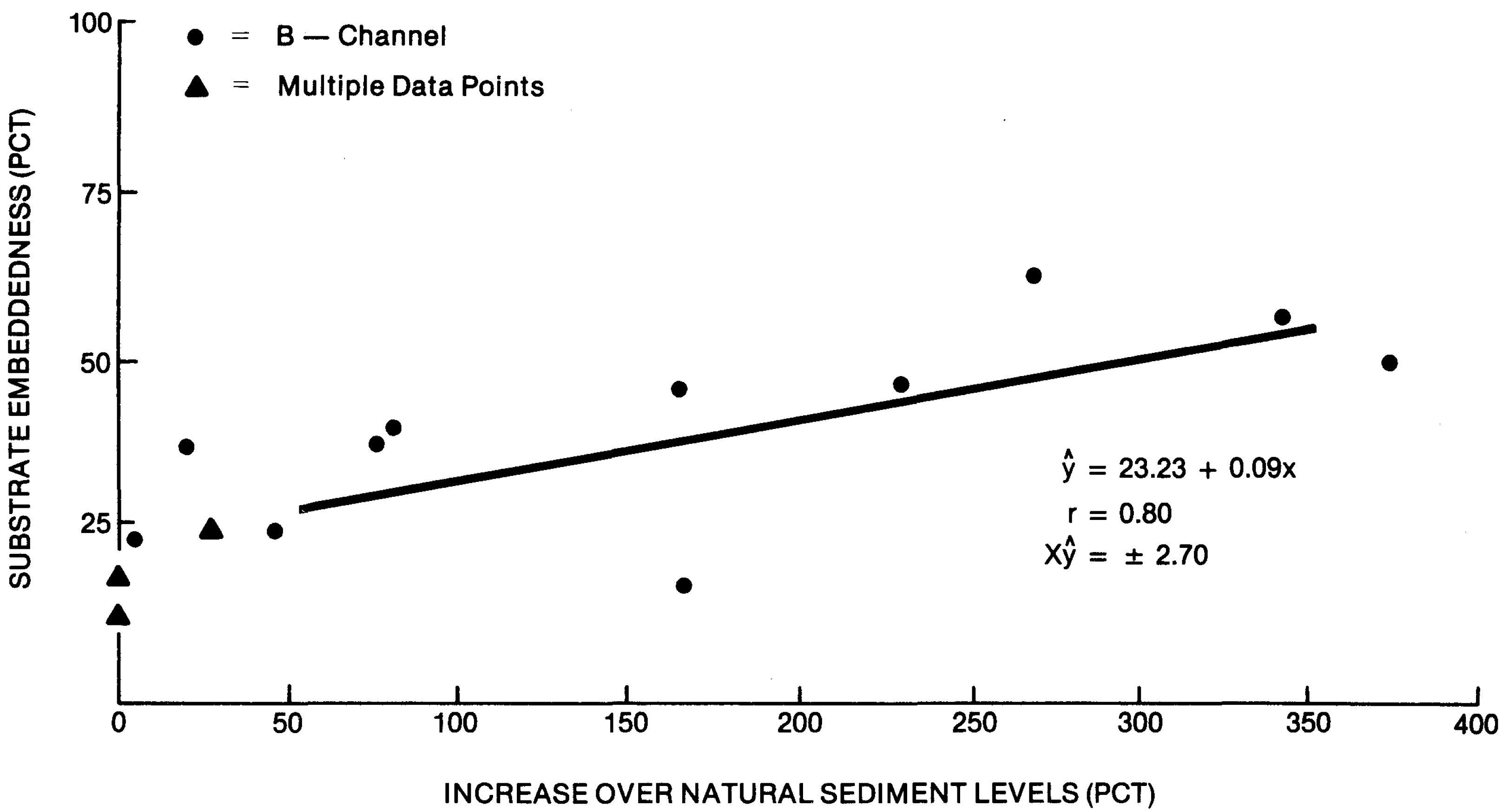



FIGURE D-2. Channel substrate embeddedness-sediment response curve for "B" channels from Clearwater and Nez Perce National Forests' data.

"C" TYPE CHANNEL

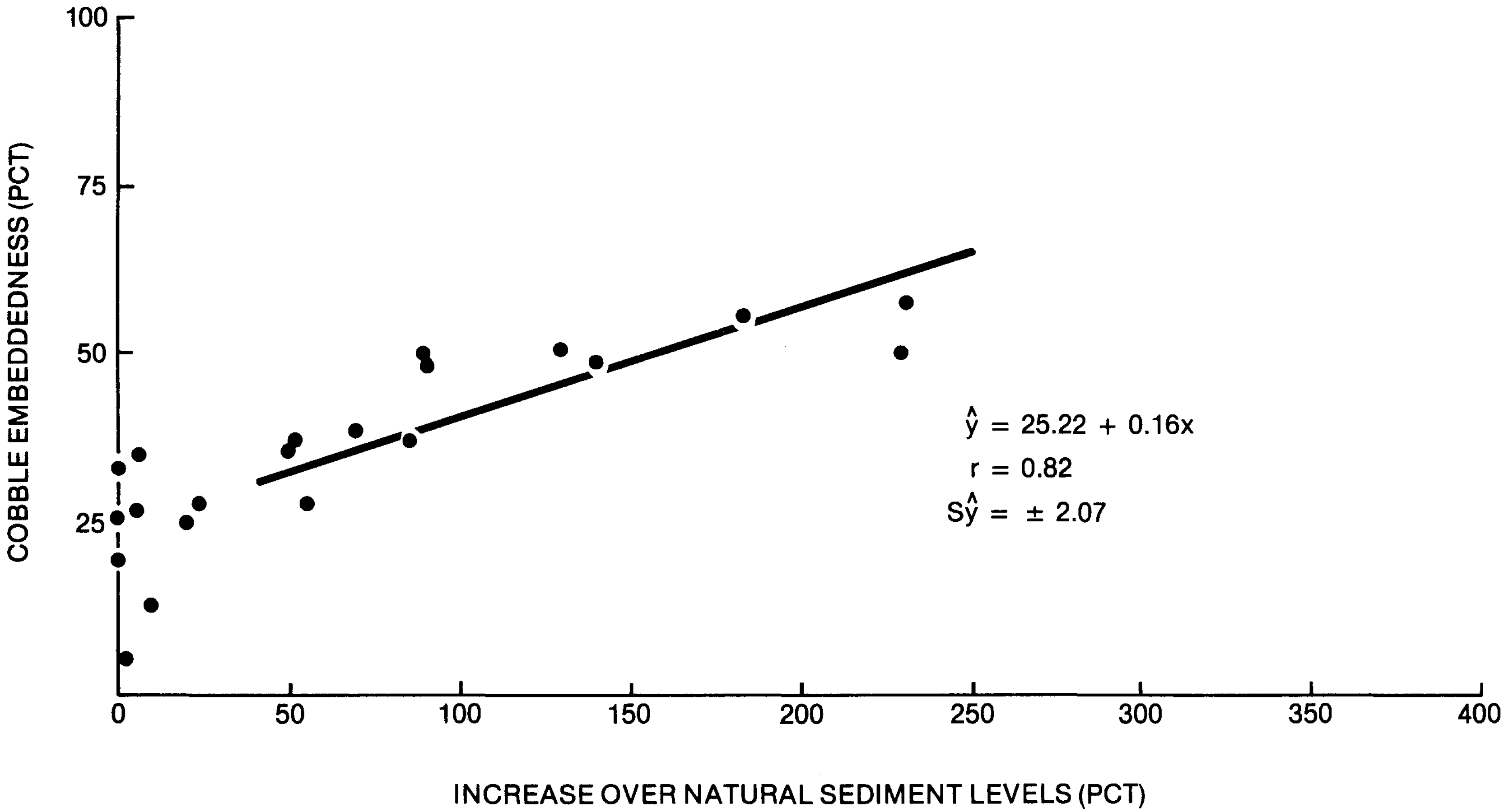



FIGURE D-3. Sediment-substrate embeddedness response curve for "C" channels from Clearwater and Nez Perce National Forests' data.

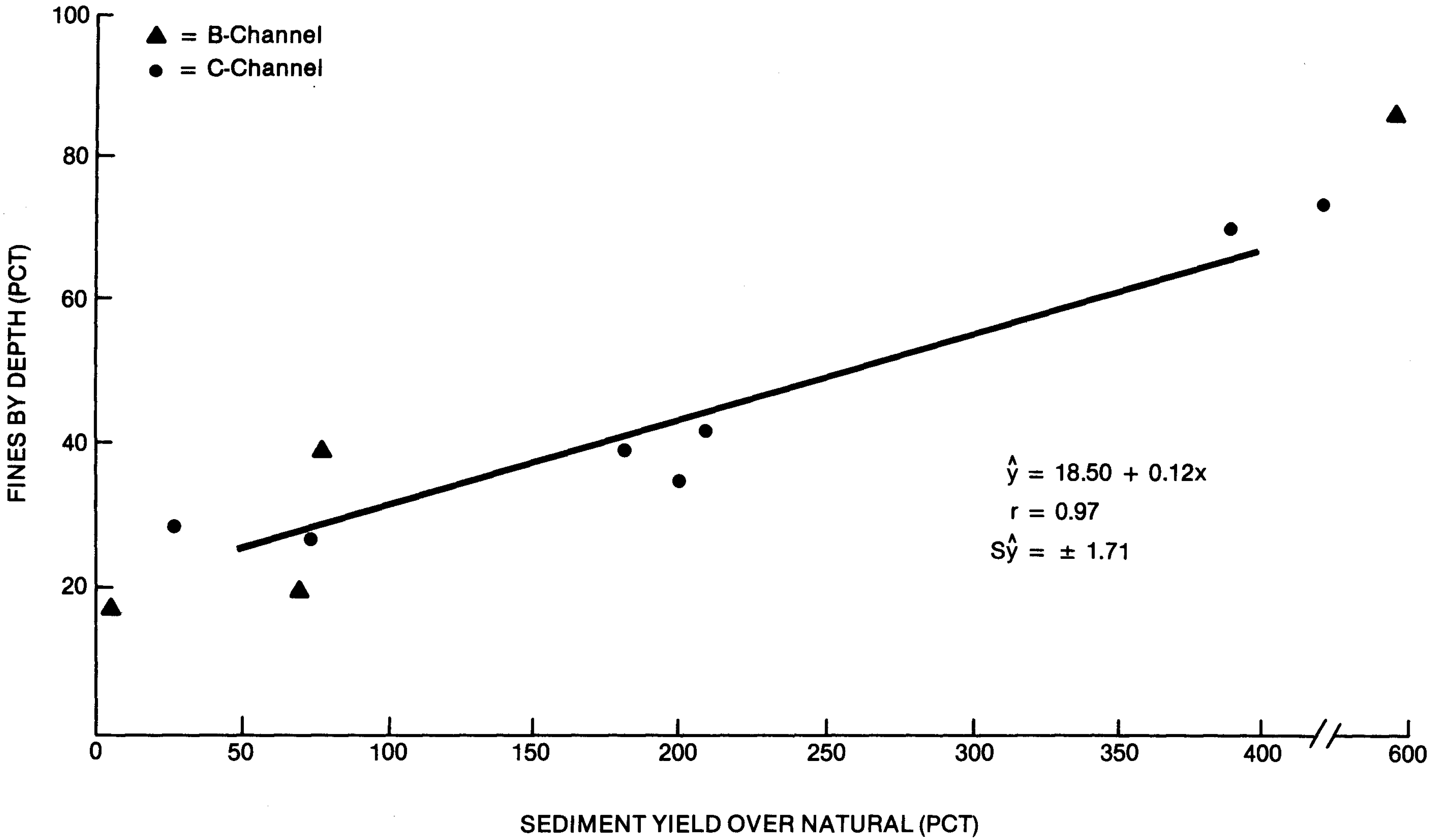



FIGURE D-4. Sediment yield over natural versus fines by depth response curve for "B" and "C" channels combined from Clearwater and Nez Perce National Forests' data.

APPENDIX E

Habitat-Fish Response Curves

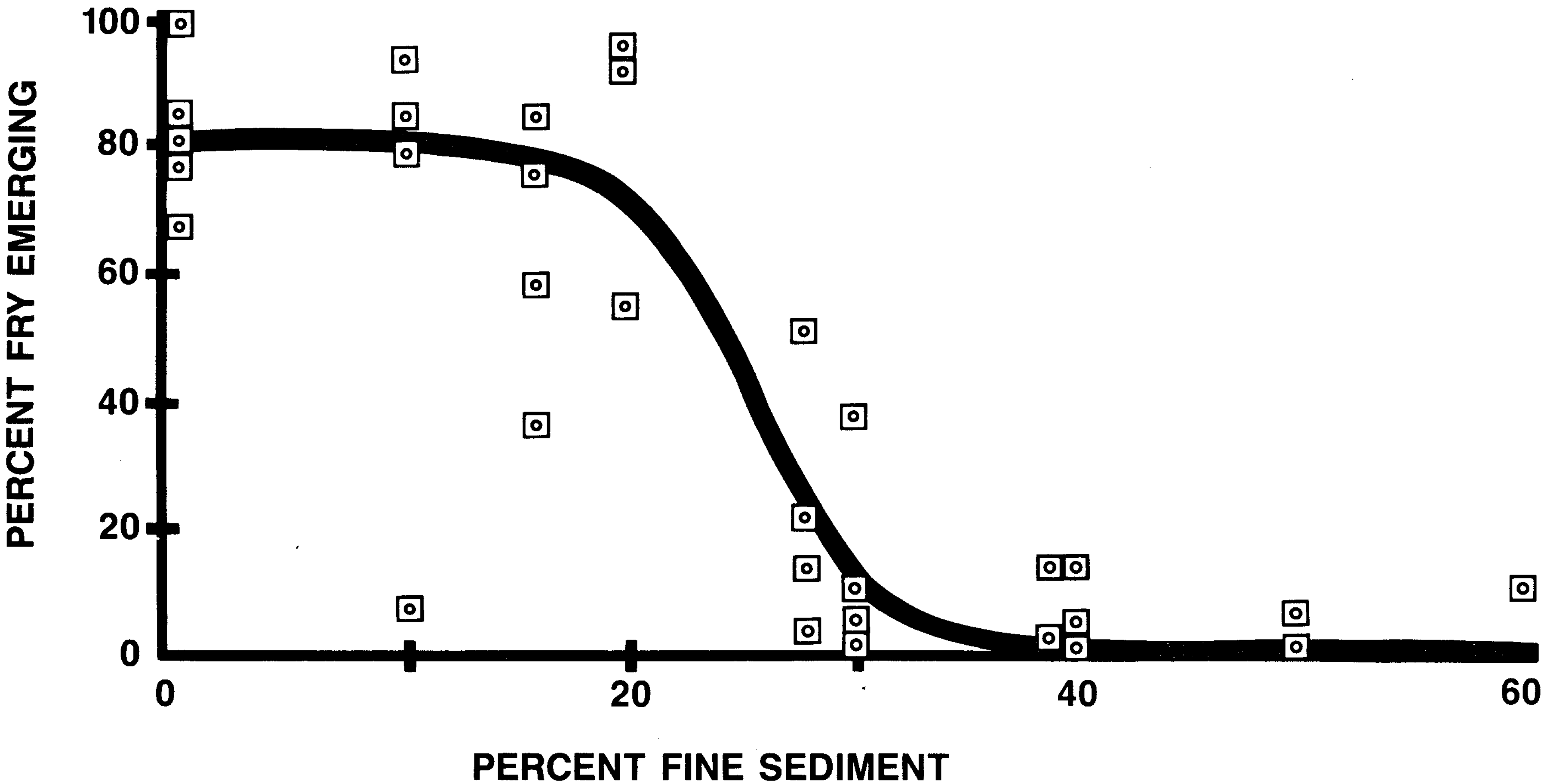



**FIGURE E-1. Fine sediment by depth versus alevin (Fry) emergence response curve for rainbow steelhead trout.**

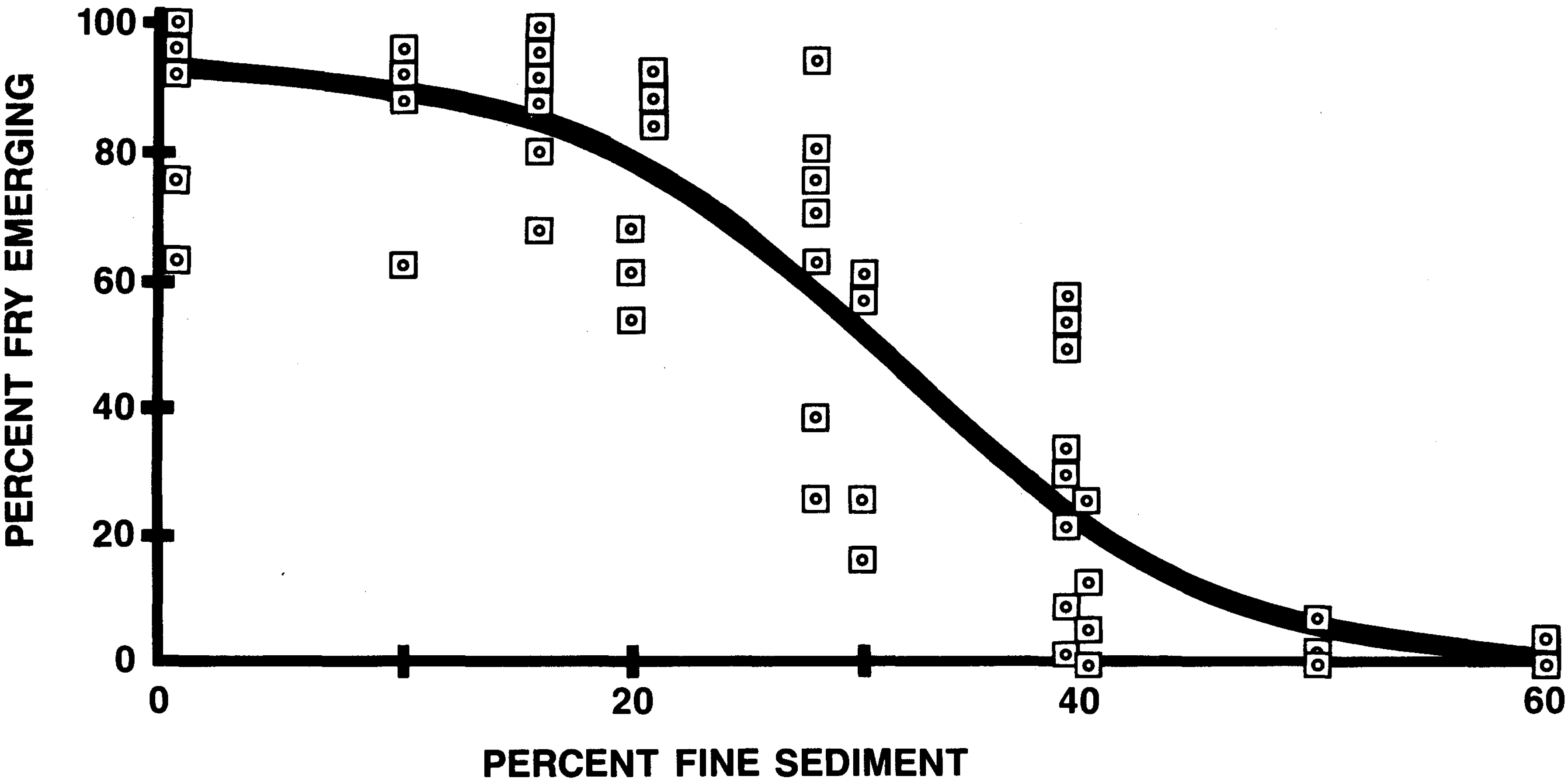



FIGURE E-2. Fine sediment by depth versus alevin (Fry) emergence response curve for chinook salmon.

**SUMMER REARING CAPACITY "RUN"**

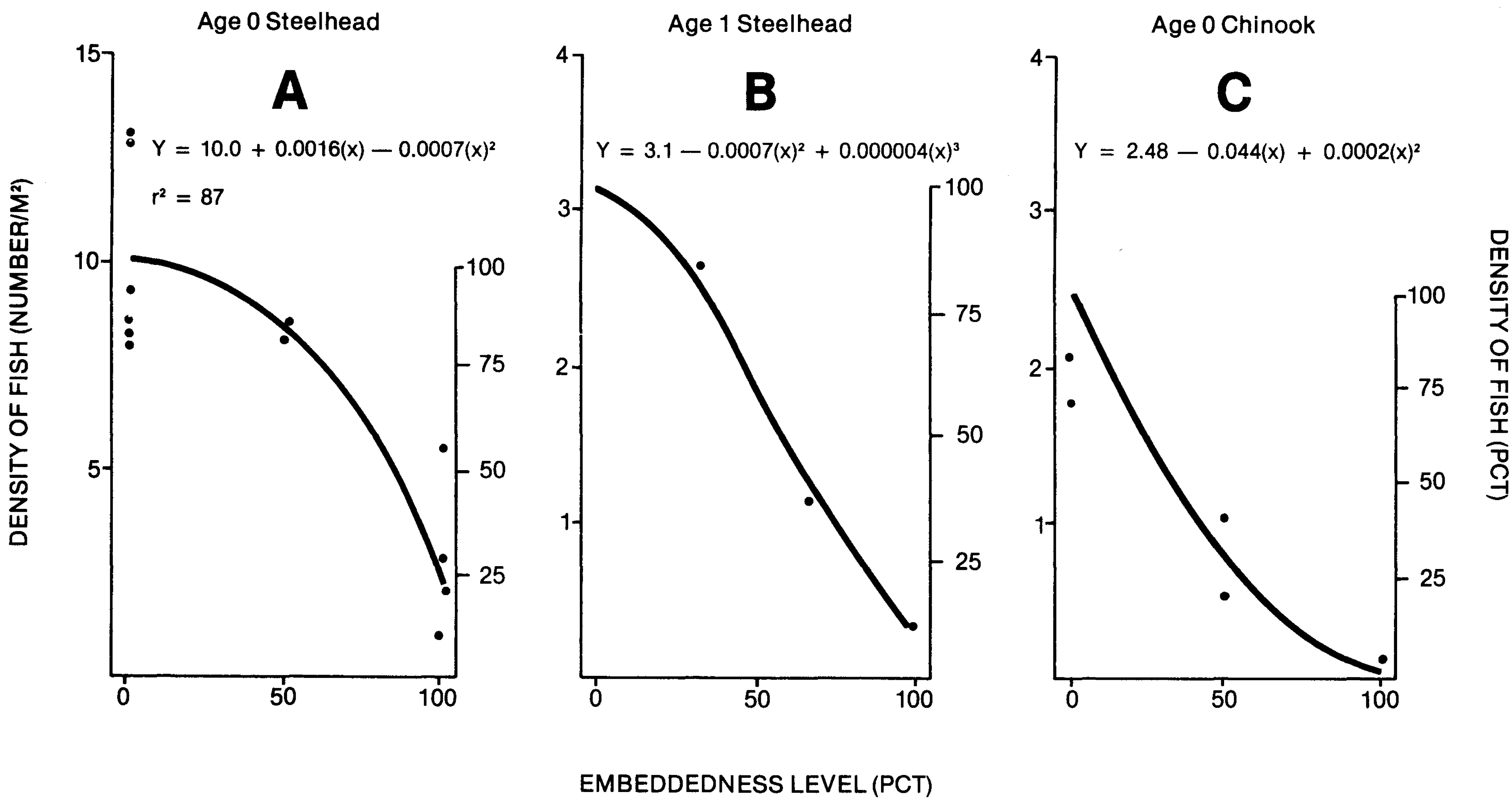



FIGURE E-3. Relationship between summer rearing capacity (density of fish in numbers of fish /m² and as a percentage) and substrate embeddedness in runs for age 0 and 1 steelhead trout and age 0 chinook salmon (Bjornn et. al. 1977).

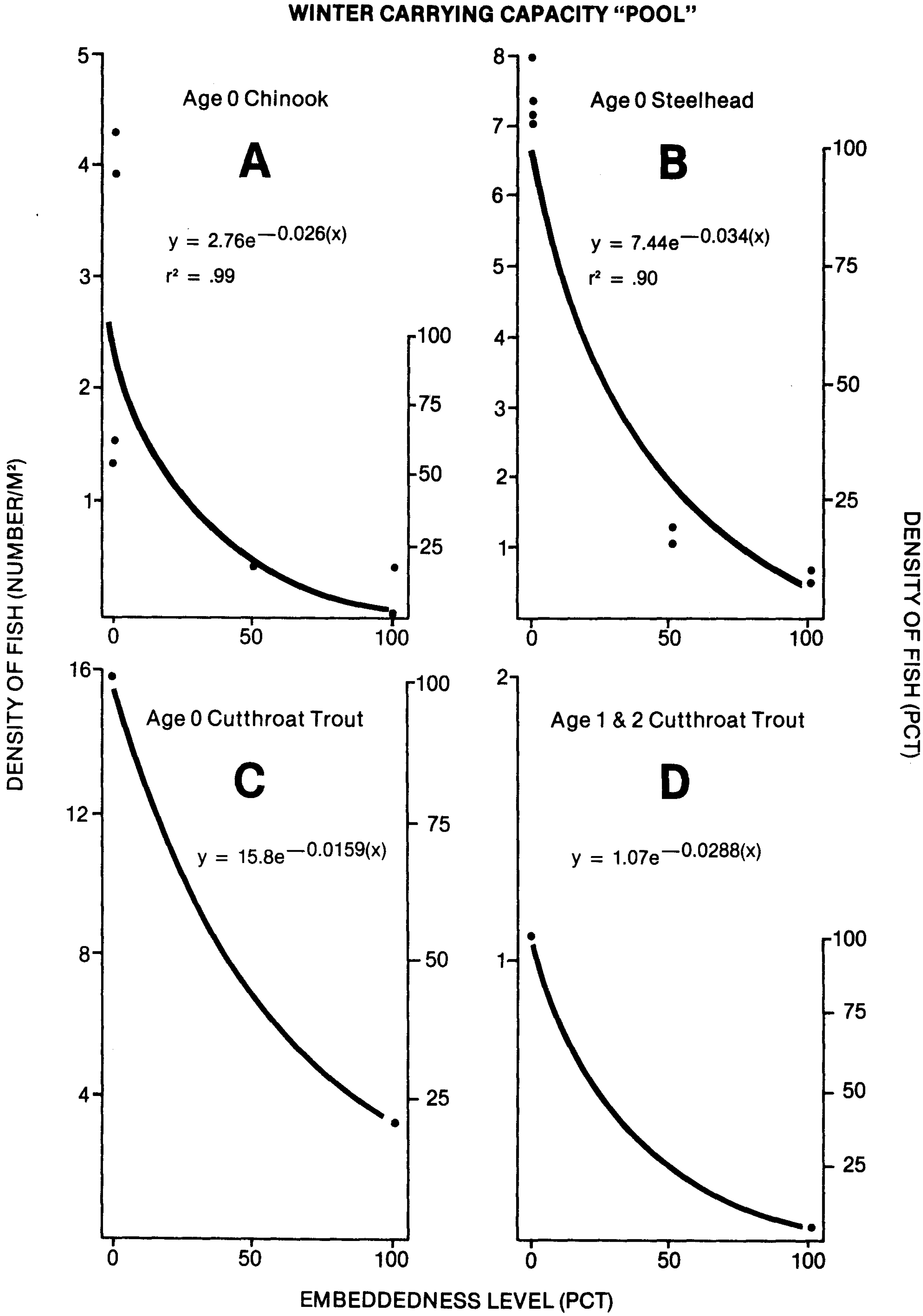



FIGURE E-4. Relationship between winter carrying capacity of pools (density of fish in numbers of fish/m² and as a percentage) and substrate embeddedness for age 0 chinook salmon, steelhead, and cutthroat trout and age 1 and 2 cutthroat trout. Based on the shape of the relationships for chinook salmon (A) and steelhead (B) a curvilinear relationship was used for cutthroat trout (C and D) between two data points.

# APPENDIX F

## Equations for Response Curves

## Equations for Response Curves

| Equation | Figure No. | Equation | Statistical Parameters: Correlation Coefficient | Coefficient Significance Level | Sample size | Sy[1/] (+ or -) |
|---|---|---|---|---|---|---|
| A | D-1 | $y=20.08 + 0.09(x)$ | 0.77 | 0.05 | 21 | 3.14 |
| B | D-2 | $y=23.23 + 0.09(x)$ | 0.80 | 0.05 | 17 | 2.70 |
| C | D-3 | $y=25.22 + 0.16(x)$ | 0.82 | 0.05 | 20 | 2.07 |
| D | D-4 | $y=18.50 + 0.12(x)$ | 0.97 | 0.01 | 11 | 1.71 |
| E[2/] | E-1 | $y=\dfrac{80.73}{1 + e^{(-9.425 + 0.3677)(\text{fine sediment})}}$ | | | | |
| F[2/] | E-2 | $y=\dfrac{92.95}{1 + e^{(-4.559 + 0.1442)(\text{fine sediment})}}$ | | | | |
| G | E-3(A) | | | | | |
| | actual[a] | $y=10.0 + 0.0016(x) - 0.0007(x)^2$ | | | | |
| | percentage[b] | $y=100.0 + 0.016(x) - 0.007(x)^2$ | | | | |
| | | | 0.87 | 0.001 | 12 | |
| H | E-3(B) | | | | | |
| | actual | $y=3.11 - 0.0007(x)^2 + 0.000004(x)^3$ | | | | |
| | percentage | $y=100.0 - 0.0228(x)^2 + 0.00014(x)^3$ | | | | |
| | | | 0.99 | <0.005 | 5 | |
| I | E-3(C) | | | | | |
| | actual | $y=2.48 - 0.044(x) + 0.0002(x)^2$ | | | | |
| | percentage | $y=100.0 - 1.79(x) + 0.0081(x)^2$ | | | | |
| | | | 0.92 | 0.01 | 8 | |
| J | E-4(A) | | | | | |
| | actual | $y=2.76e^{-0.026(x)}$ | | | | |
| | percentage | $y=100.0e^{-0.034(x)}$ | | | | |
| | | | 0.99 | <0.005 | 7 | |

1/ Sy = sample standard deviation of y as an estimate of a new point y (Snedecor and Cochran 1968).

2/ See Appendix H.

Appendix F -- Con't

| | | | | | |
|---|---|---|---|---|---|
| K | E-4(B) | | | | |
| | actual | $y=7.44e^{-0.034(x)}$ | | | |
| | percentage | $y=100.0e^{-0.026(x)}$ | | | |
| | | | 0.90 | 0.01 | 8 |
| L | E-4(C) | | | | |
| | actual | $y=15.8e^{-0.0159(x)}$ | | | |
| | percentage | y=100.0e-0.0159(x) | | | |
| M | E-4(D) | | | | |
| | actual | $y=1.07e^{-0.0288(x)}$ | | | |
| | percentage | $y=100.0e^{-0.0288(x)}$ | | | |

[a] Based on actual data points

[b] Data points adjusted to a percentage in relation to a y-intercept of 100%

[c] One degree of freedom

# APPENDIX G

## EXAMPLE

## A Sediment-Fish Response Analysis of the South Fork Salmon River

## Introduction

The South Fork Salmon River drainage (Fig. G-1) is approximately 324,000 hectares located in central Idaho. The drainage is characterized by steep slopes, highly erodible soils and high climatic stresses typical of the 41,000 square-kilometers Idaho Batholith (Platts and Megahan 1975). These conditions, combined with logging road construction and rain-on-snow, caused severe impacts to chinook spawning habitat during the mid-1960's (Arnold and Lundeen 1968, Megahan and others 1980, Platts 1970, Platts and Megahan 1975).

The South Fork historically contained Idaho's largest run of summer chinook salmon (Richards 1963). This run and other Columbia Basin chinook salmon were studied pursuant to the Endangered Species Act (Horner and Bjornn 1981) because of severe long-term declines in abundance. Bjornn (1971) concluded that declines in redd counts at several major spawning areas corresponded to the greatest impacts from sedimentation. Platts (1972) pointed out that because of the life cycle of salmon populations and downriver effects, the fish population might not respond perceptibly to changing habitat conditions in the South Fork.

Chinook salmon smolt production could be expected to decline in the South Fork when increased quantities of fine particles exerted a density independent source of mortality during the egg to emergent fry life stage. Research by Bjornn (1973) and McCuddin (1977) demonstrated a decline in egg to emergent fry survival with increasing relative amounts of fine sediment (<6.35 mm diameter) in egg holding substrate.

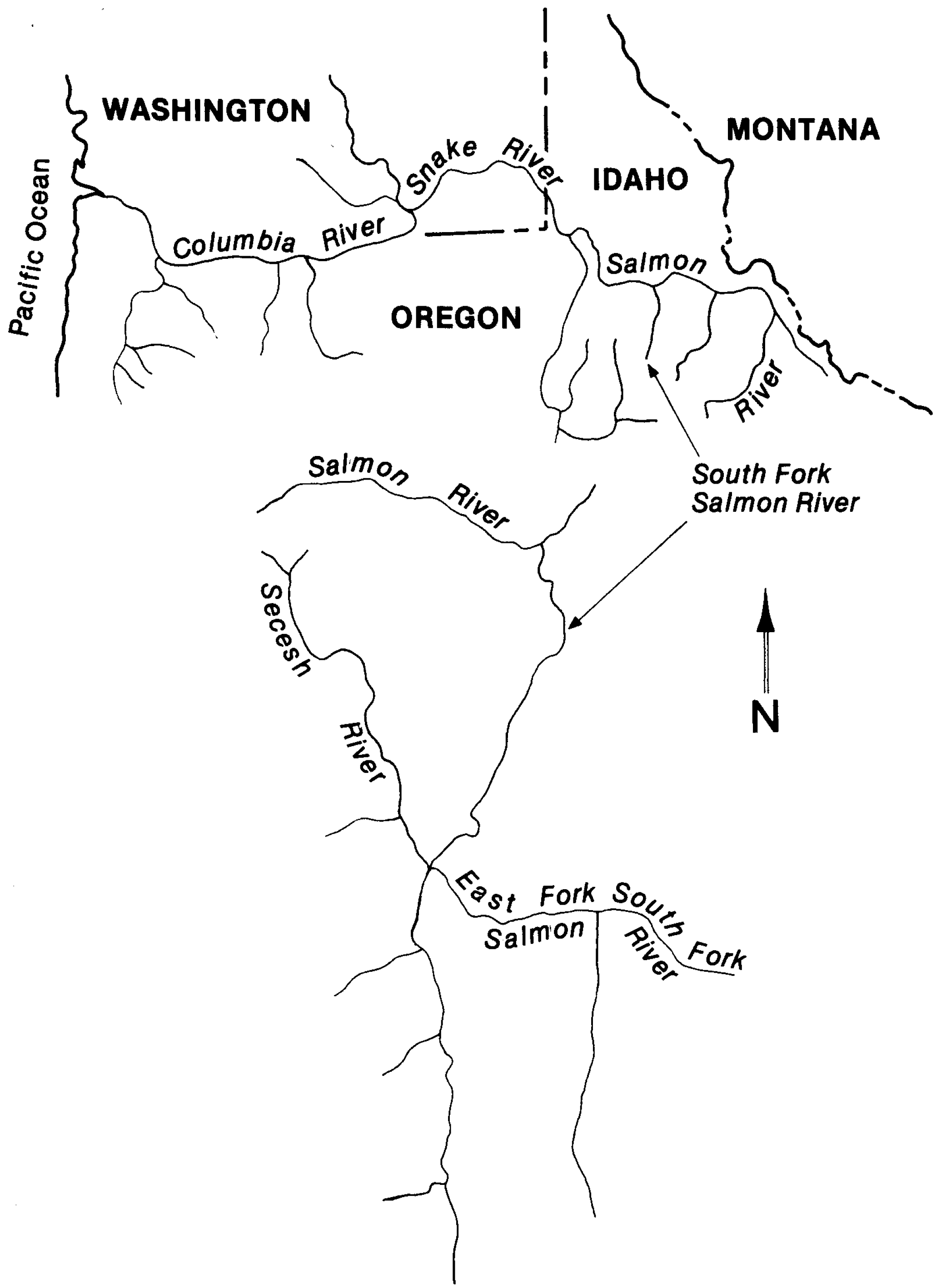



FIGURE G-1. The South Fork of the Salmon River is located in central Idaho. Major tributaries include the Secesh River and the East Fork.

Available data on historical sediment production, spawning gravel condition, relative egg to emergent survival, and redd counts has been combined in order to evaluate the historic influences of fine sediment on the chinook salmon population of the South Fork. This analysis is being used as a planning tool to assess future management options and their possible effects on chinook salmon.

## Sediment Production

Sediment production in the South Fork peaked in the mid-1960's (Figure G-2) due to logging road construction in the upper half of the watershed (Mickelson and others 1973).

In order to validate planning models, the Payette National Forest refined the "Guide for Predicting Sediment Yields from Forested Watersheds" (Cline and others 1981) by including more local data (Jahn and Kulesza, 1982). Sediment yields were developed to fit a Forest planning model (FORPLAN) format and yields were calculated for 5 decades beginning in 1935 for the entire South Fork Salmon River drainage (Figure G-3).

Modeled sediment yields reflect the same distribution over time as those determined from earlier field observation. The sharp decline in sediment yield from the mid to late 1960's leveling off toward a more stable yield can be seen in both sets of information.

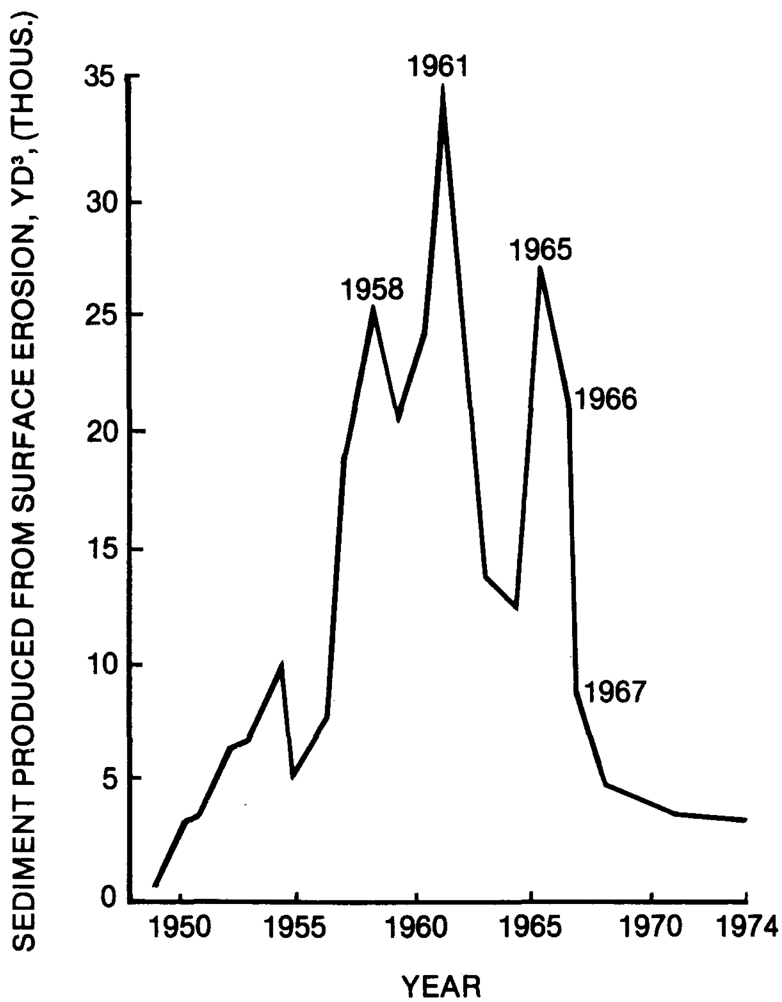



FIGURE G-2. A year-by-year estimate of sediment production due to logging roads was made by Michelson, Kulesza, Stephenson, and Platts (1973) for the South Fork Salmon River upstream from its confluence with the East Fork. These estimates show peak sediment production occurring in the mid-1960's and declining with the implementation of a moratorium on new roads and a watershed rehabilitation program.

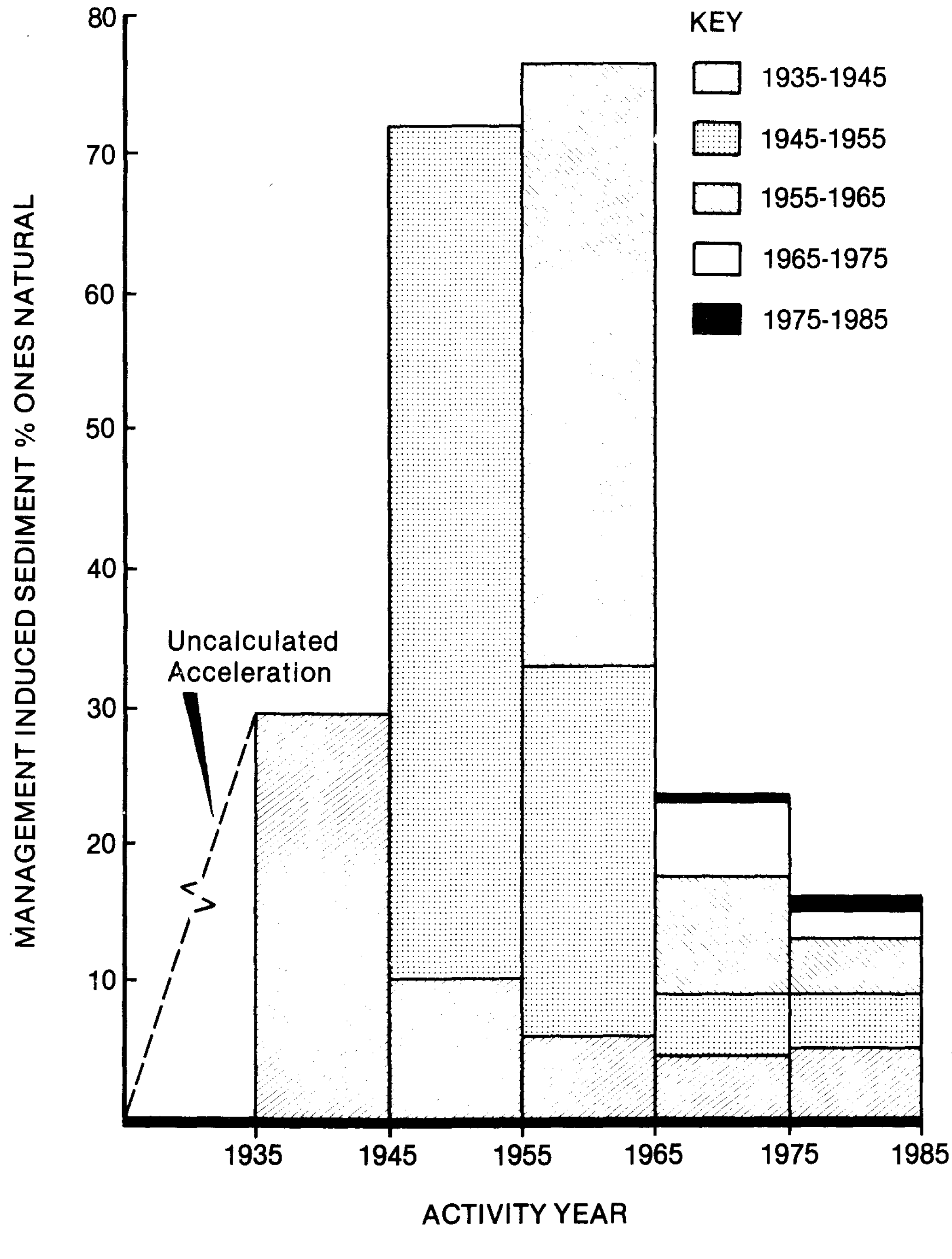



FIGURE G-3. Management induced sediment production for the South Fork Salmon River drainage utilizing FORPLAN decade long yields. The key identifies the decade in which a particular road or other activity began. The cumulative effect is displayed as the FORPLAN type model accumulates yields. Recovery of drainage is modeled by reduced histogram heights from 1965.

## Riverbed Conditions

The decline in sediment yield was paralled by a decrease in the quantity of visible fine sediment deposited on chinook spawning areas (Figure G-4 after Platts and Megahan 1975). This paralleled trend in deposition and yield can be assumed to reflect the real ability of the river system to yield, deposit, and transport fine sediment.

The major concern relating to spawning area condition is not the amount of fine material on the surface but the amount in the gravel where the chinook will deposit their eggs. Megahan and others (1980) summarized the work of several studies (Figure G-5) documenting a decline in the amount of fine sediment within spawning substrates. Corley and Newberry (1982) reported that the Poverty spawning area was cleaned significantly (P=0.05, Newman-Kieuls analysis) from a high of near 37 percent (fine particles <6.35 mm) in 1975 to lows of 28 percent for 1980 and 31.2 percent for 1982.

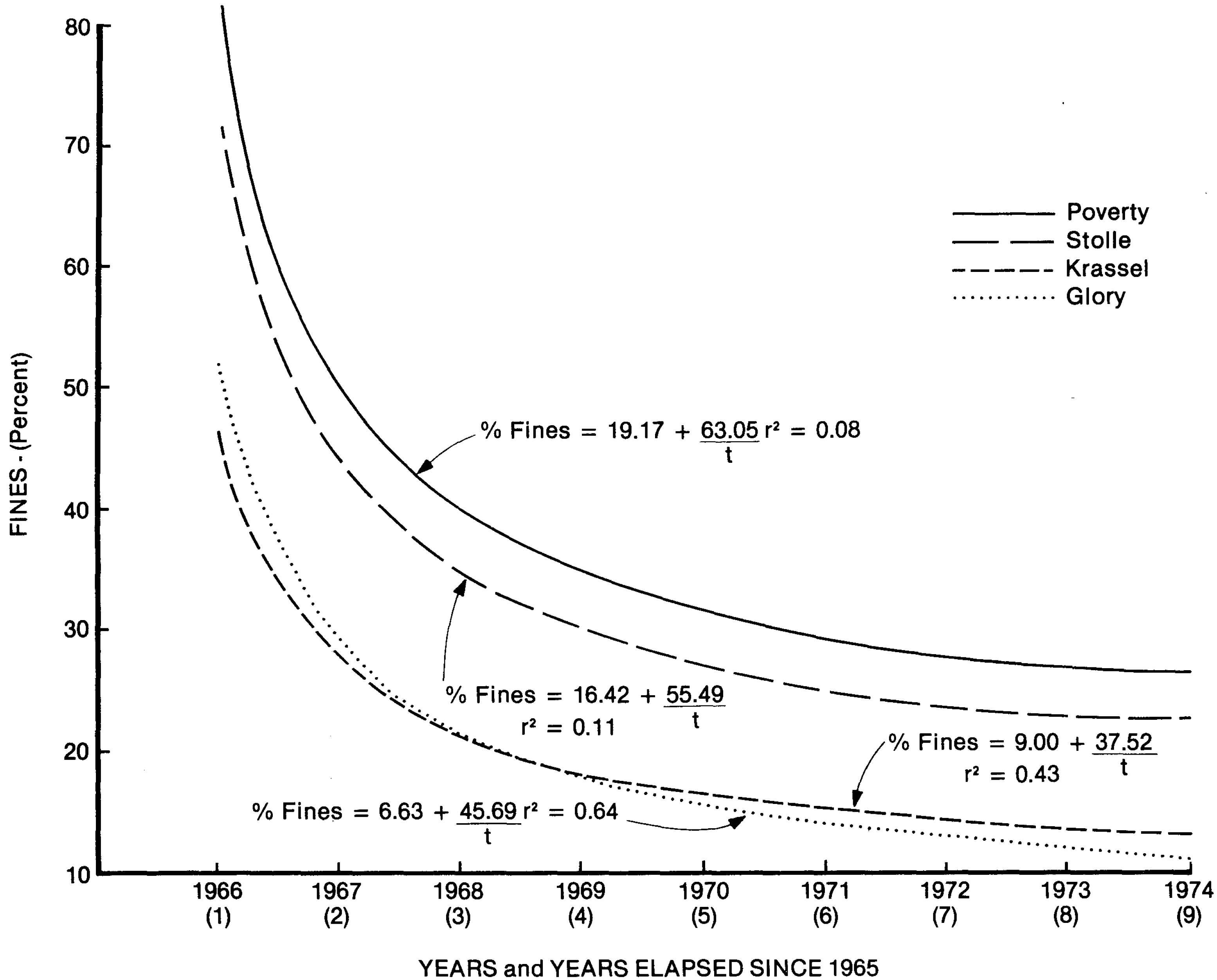



FIGURE G-4. Platts and Megahan (1975) reported that ocular estimates of fine particles on the surface of four major spawning areas (Poverty, Stolle, Krassel, and Glory) declined from the late 1960's through the early 1970's.

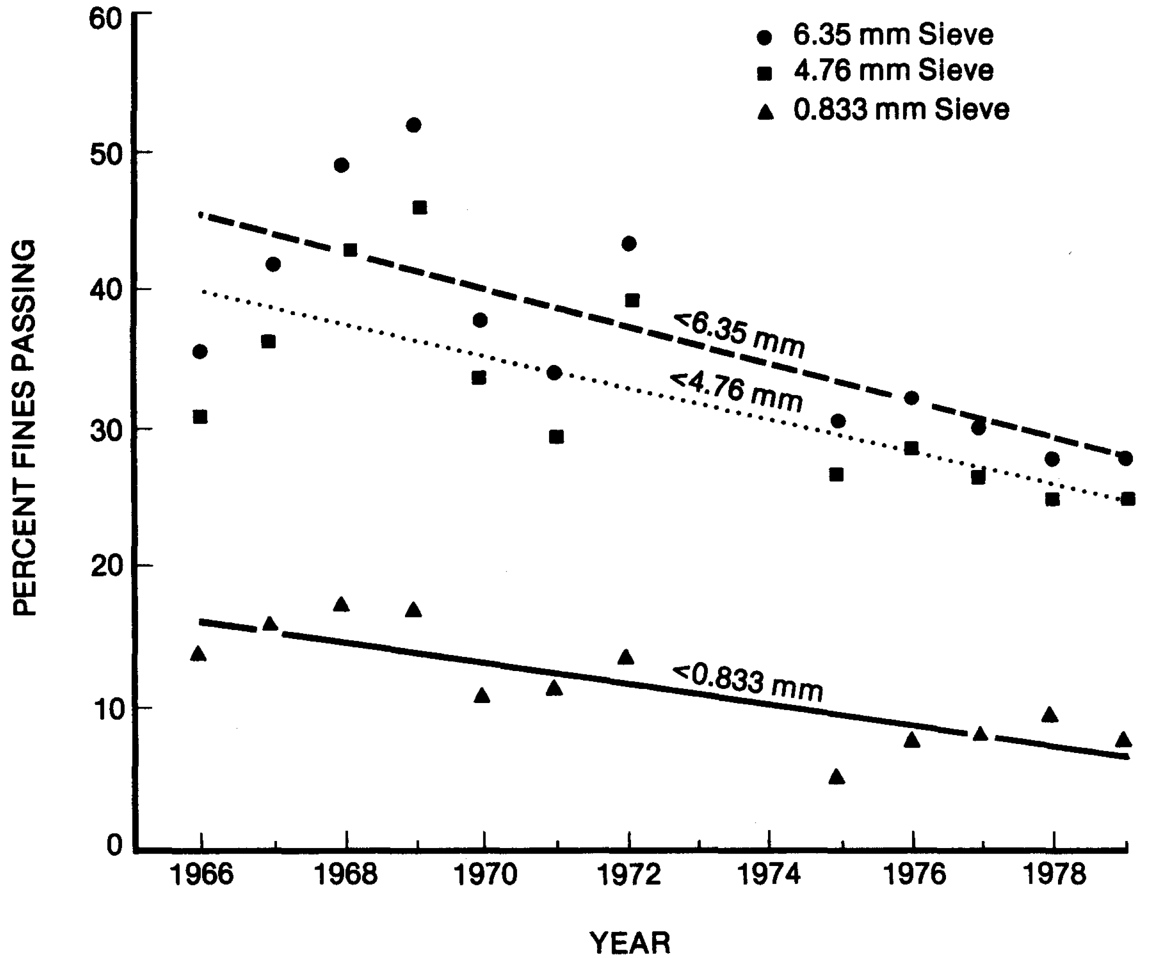



FIGURE G-5. Megahan, Platts, and Kulesza (1980) summarized core sample data from some major chinook salmon spawning areas documenting the declining quantities of fine sediment from the late 1960's through the 1970's.

Relationship to Chinook Survival

We can describe the changes relative in chinook salmon survival over time by utilizing the relationships developed by McCuddin (1977) and Bjornn (1973) for percentage of fine sediment in spawning areas and alevin emergence (Appendix E) and data available on the Poverty spawning area (Figure G-6). Based on data from Ortman (1968a) and Megahan and others (1980) the late 1960's condition of the Poverty spawning area should have yielded the lowest alevin emergence with 37 percent or more fine sediment in the substrate. Fines have decreased; alevin emergence has steadily improved since that time.

Maximum alevin emergence would occur in the Poverty spawning area when it contained the lowest percentage of fine sediment. Natural conditions can be approximated by extending the trends established in Megahan and others (1980). For Poverty natural quantities of fine sediment should be close to 25 percent. This is in agreement with low amounts of sediment reported by Lund (1982a, 1982b), Burns (1978), and others. Natural amounts of sediment in the Poverty spawning gravel should yield near maximum alevin emergence.

## Population Relationships

Comparison against existing fish population data suggests that the relationships are reasonable. We have assumed that redd counts, dam counts, and fish weir counts are "reasonably" accurate. Smolt production is calculated (Table 1) for time periods when numbers of spawning adults (Table 2) utilized the gravel qualities previously documented. If the 1965-68 spawning adults (1,374) are assumed to produce near maximum smolt numbers (36,800) under relatively poor environmental conditions, then 40,000 smolts approximates the capacity of the river. This seems to be reasonable because approximately the same number of spawning adults (1,460) produced a greater number of smolts (190,700) in 1951-54 under better habitat conditions. The major difference in the freshwater habitat between the two time periods is sedimentation.

If the 40,000 smolt capacity is adjusted upward to reflect increased proportional alevin emergence, as in the Poverty example, then the capacity of the South Fork can be approximated.

The smolt producing capacity of the South Fork can be expressed as a reproduction curve between the number of adult spawners and subsequent number of smolts produced. Such relationships have been described by Beverton and Holt (1957), Ricker (1975), and Silliman (1971).

Table 1.--Calculations of summer chinook salmon smolt production from the South Fork of the Salmon River, Idaho.

| Col. 1 | Col. 2 | Col. 3 | Col. 4 | Col. 5 | Col. 6 | Col. 7 | Col. 8 | | Col. 9 |
|---|---|---|---|---|---|---|---|---|---|
| Spawning escapement year | Four years later | Redd count RE:Col. 2 | Col. 3÷1.5 $\frac{\text{redds}}{o_x}$ | 2 x Co. 4 (50:50 sex ratio) | Idaho harvest | Total run = Col. 6+ | Smolt to adult survival | | Number of smolts produced by Col. 1 = Col. 7÷Col. 8 |
| 1951 | 1955 | 3376 | 2251 | 4502 | 4180 | 8682 | 0.05* | | 173600 |
| 1952 | 1956 | 2739 | 1826 | 3652 | 4620 | 8272 | 0.05* | | 165400 |
| 1953 | 1957 | 3505 | 2337 | 4674 | 8580 | 13254 | 0.05* | | 265100 |
| 1954 | 1958 | 1983 | 1322 | 2644 | 5280 | 7924 | 0.05* | | 158500 |
| | | | | | | | | MEAN | 190700 |
| 1965 | 1969 | 1013 | 675 | 1350 | 0 | 1350 | 0.04** | | 33800 |
| 1966 | 1970 | 720 | 480 | 960 | 0 | 960 | 0.04 | | 24000 |
| 1967 | 1971 | 684 | 456 | 912 | 0 | 912 | 0.03 | | 30400 |
| 1968 | 1972 | 884 | 589 | 1178 | 0 | 1178 | 0.02 | | 48900 |
| | | | | | | | | MEAN | 36800 |
| 1972 | 1976 | 326 | 217 | 434 | 0 | 434 | 0.01 | | 43400 |
| 1973 | 1977 | 334 | 223 | 446 | 0 | 446 | 0.026 | | 17200 |
| 1974 | 1978 | 455 | 303 | 606 | 0 | 606 | 0.01 | | 60600 |
| 1975 | 1979 | 171 | 114 | 228 | 0 | 228 | 0.004 | | 57000 |
| | | | | | | | | MEAN | 44500 |

Col. 1, Col. 2, Col. 3: are from Horner and Bjornn, 1981.
Col. 4: 1.5 Redds/$o_x$ from Ortman, 1968b.
Col. 5: 50/50 sex ratio approx. from Idaho Fish and Game internal data.
Col. 6: based on 22 percent of total Idaho chinook harvest being from So. Fork. See Horner and Bjornn, 1981.
Col. 8: from Park's (1980) table 5 by dividing "total adults returning" by "population at upper dam".
* Approximated at 0.05 based on known max. survival for steelhead, etc. on coast, Washington State Game Dept. internal data.
** Assumed same as subsequent out-migration year.

Table 2.--Calculation of adult spawning summer chinook salmon population in the South Fork of the Salmon River.

| Col. 1 Spawning escapement year | Col. 2 Mean No. redds | | Col. 3 Co. 2÷1.5 redds/$o_x$ | Col. 4 2 x Co. 3 (50:50 sex ratio) = spawning population |
|---|---|---|---|---|
| 1951-54 | So. Fk. | 904 | 603 | 1206 |
| | Secesh | 94 | 63 | 126 |
| | East Fk. | 96 | 64 | 128 |
| | | | | 1460 |
| 1965-68 | So. Fk. | 751 | 501 | 1002 |
| | Secesh | 118 | 79 | 158 |
| | East Fk. | 160 | 107 | 214 |
| | | | | 1374 |
| 1972-75 | So. Fk. | 313 | 209 | 418 |
| | Secesh | 35 | 23 | 46 |
| | East Fk. | 126 | 84 | 168 |
| | | | | 632 |

Col. 1 and Col. 2: are from Horner and Bjornn, 1981.
Col. 3: 1.5 Redds/$o_x$ from Ortman, 1968b.
Col. 4: 50/50 sex ratio approx. from Idaho Fish and Game internal data.

> A graph of recruits against the spawners that produced them is called a recruitment curve; reproduction curve is a more general term, applicable when the progeny are enumerated at any life-history stage. The points on such graphs tend to be rather dispersed because of environmental effects, so attempts have been made to work out possible interactions between adults and their progeny and to deduce what kind of an average curve each would produce. . . Unfortunately our knowledge of population regulatory mechanisms in nature is so slight that it is usually difficult to choose among

> different curves on this basis, so we usually fit the simple curve that looks most reasonable. However, of the two curves most used, the Ricker type is more appropriate when, (1) cannabalism of young by adults is an important regulatory mechanism, (2) when the effect of greater density is to increase the time needed by young fish to grow through a particularly vulnerable size range, or (3) when there is a time lag in the response of a predator or parasite to the abundance of the young fish it consumes.
>
> The Beverton-Holt curve is likely to be appropriate when there is a ceiling of abundance imposed by available food or habitat, or when a predator can adjust its predacious activity immediately and continuously to the abundance of the prey under consideration (Ricker, 1975).

We constructed Beverton and Holt (1957) type curves utilizing the previously described adult and smolt numbers (Figure G-7). The examination of these curves can be useful to determine viable population or state agency objectives relative to fish production. The population analysis is consistent with all of the other information available on the South Fork.

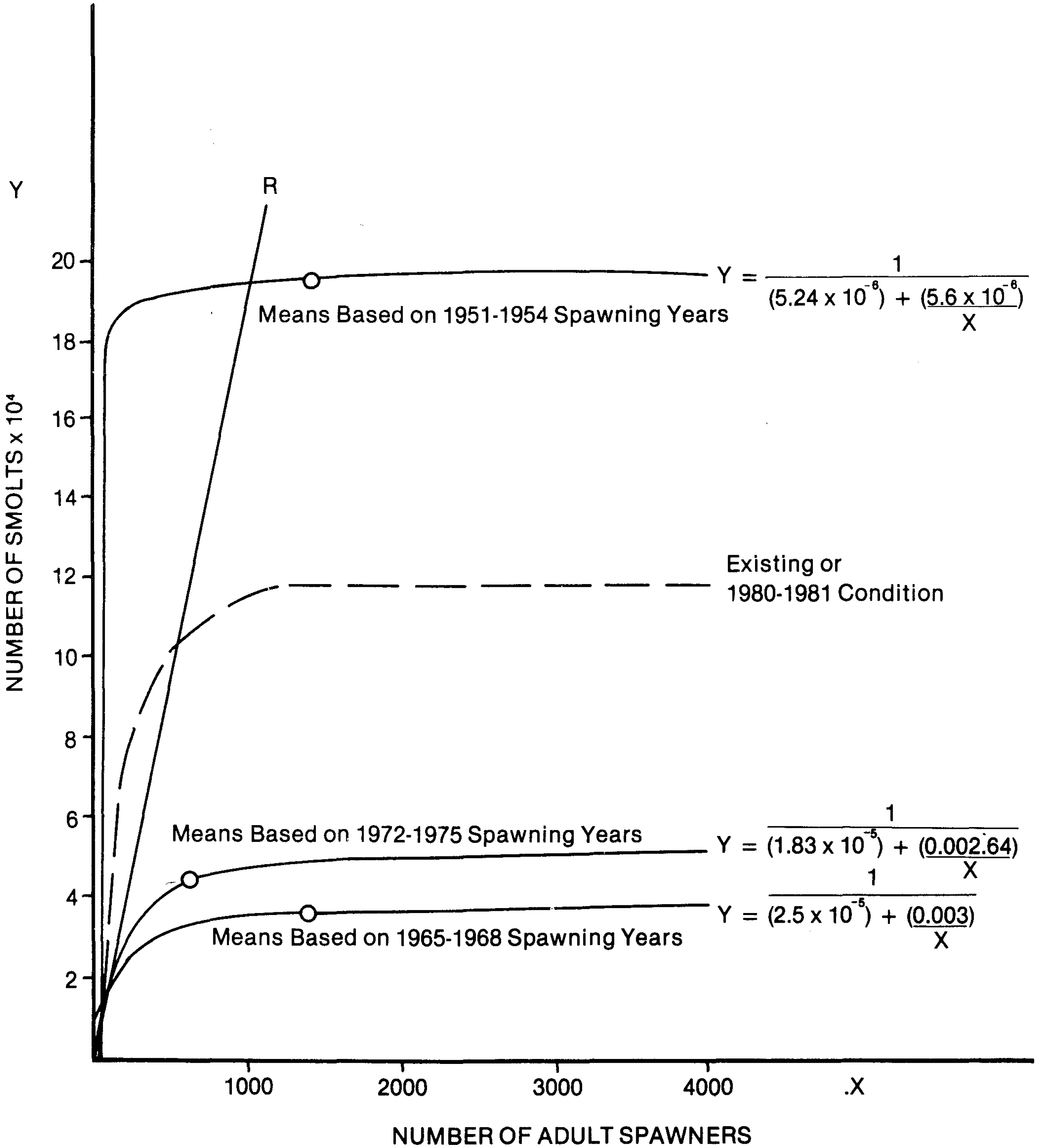



FIGURE G-7. Existing reproduction curve (1980-81) for the South Fork Salmon River summer chinook relative to natural potential (1951-54) and following the 1964-65 storm (1965-68). The replacement line (R) is for 0.005 smolt to adult survival. Each curve is considered fixed for the quantity of sediment produced by land disturbing activities during corresponding years.

# APPENDIX H

## Statistical Analysis for Curves Used to Determine Chinook Salmon and Rainbow Steelhead Egg to Emergent Alevin Survival

# Statistical Analysis
for

## WILLIAM PLATTS

Statistician: Gordon D. Booth
Date: 7 March 1984

### FITTING THE CURVES:

Several different functions were fitted to the data. I finally decided on a modification of the logistic function. It has the property of being asymptotic on the left at some point below 100% fry emergence, and also being asymptotic on the right at zero. It is S-shaped (i.e. sigmoidal) and appears to fit your data reasonably -- not perfectly.

The fitted curves are plotted with the data in Figure 1. Note the wide ranges of fry emergence for the same percent sand. This means the data are highly variable. Nevertheless, the fitted curves provide a reasonable approximation to what is going on in the data. Caution should be exercised in the use of such curves. (See discussion below.)

### HIGHEST LEVEL OF FRY EMERGENCE:

The point at which the curve crosses the Y-axis is the intercept. This represents no sand (i.e. 0%). This is the theoretical maximum rate of fry emergence. An approximate 95% confidence interval on this value places it between 84.2 and 99.8 percent emergence for Chinook salmon. This is important information. If our model is a good representation of the data, the maximum fry emergence is at least 73.6% and may be as high as 87.9% (95% confidence). Our data is too variable to allow us to claim greater precision than this.

An equivalent 95% confidence interval for Steelhead places it between 73.6 and 87.9 percent fry emergence.

### THE FITTED FUNCTION:

The equations for the two species are:

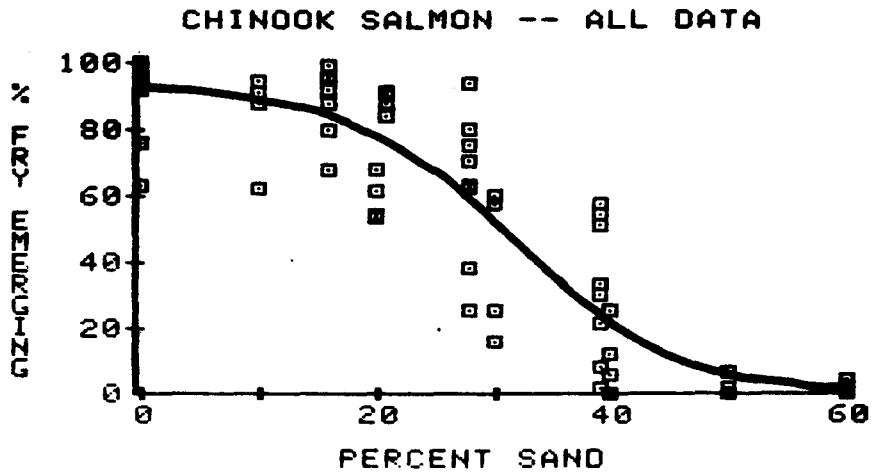
Chinook:

Emergence = 92.95 / (1 + exp(-4.559 + 0.1442 X sand))

Steelhead:

Emergence = 80.73 / (1 + exp(-9.425 + 0.3677 X sand))

These are the curves plotted with the data in Figure 1.


CHINOOK SALMON -- ALL DATA
% FRY EMERGING
PERCENT SAND
100
80
60
40
20
0
0
20
40
60

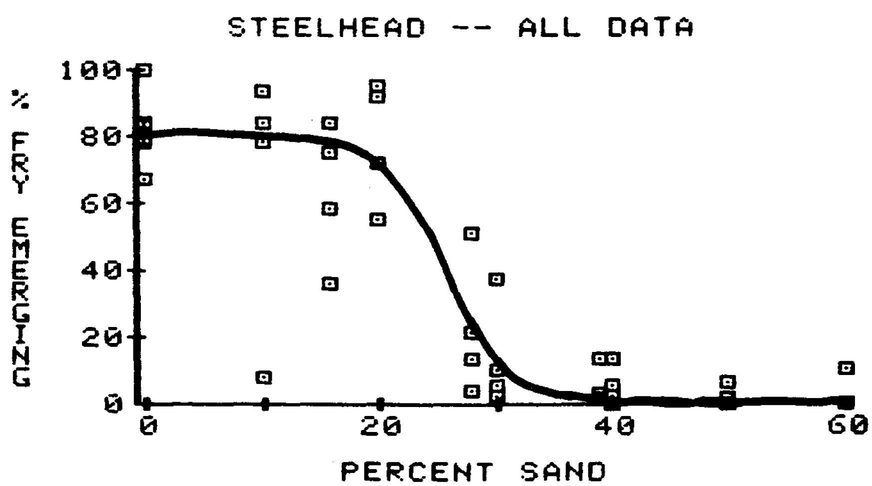

STEELHEAD -- ALL DATA
% FRY EMERGING
PERCENT SAND
100
80
60
40
20
0
0
20
40
60

Figure 1

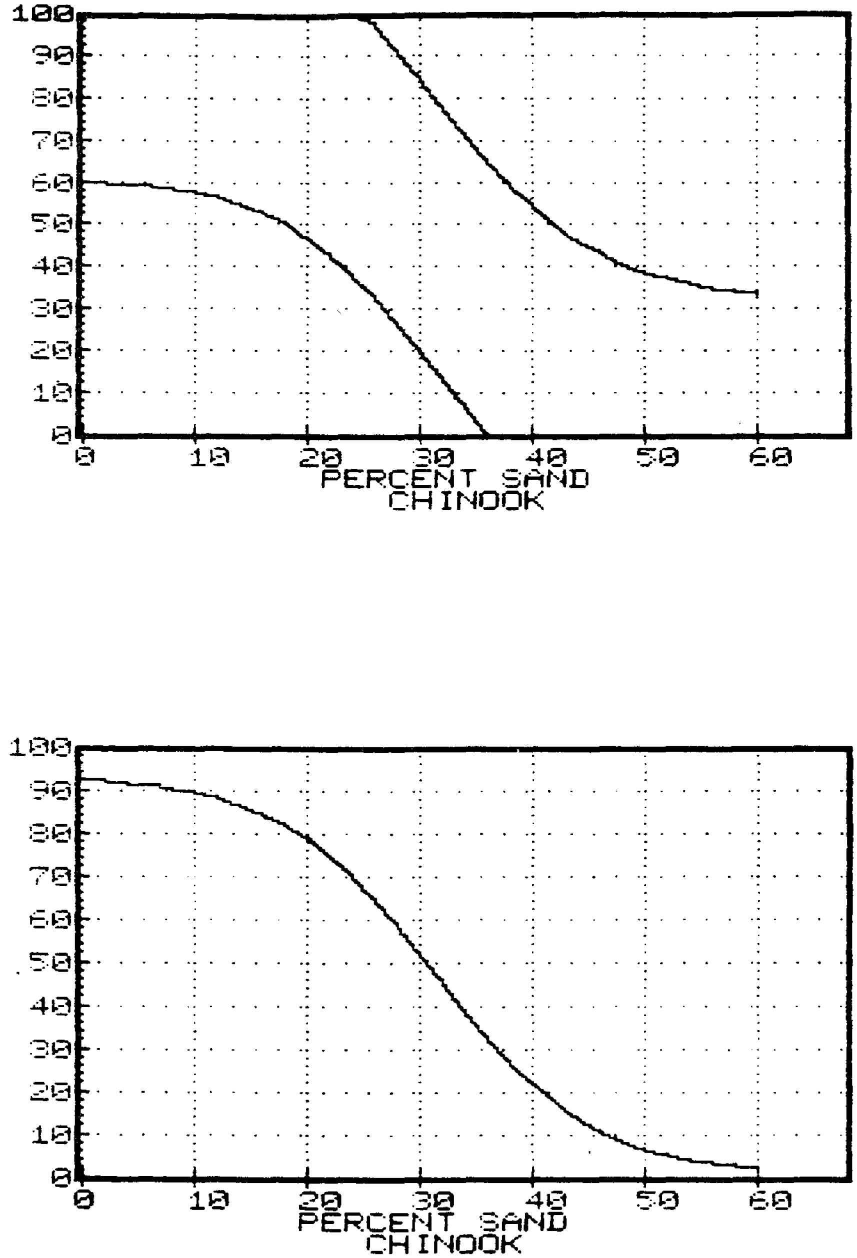
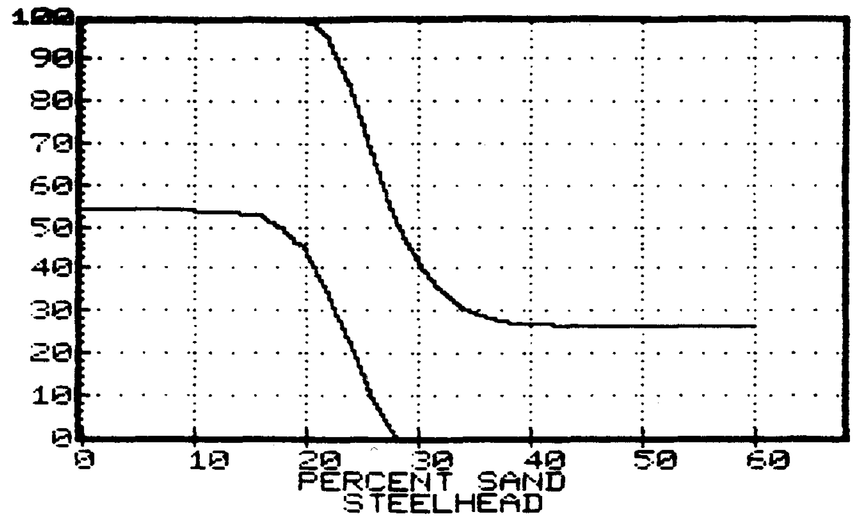

100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
PERCENT SAND
CHINOOK
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
PERCENT SAND
CHINOOK

Figure 2


100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
PERCENT SAND
STEELHEAD

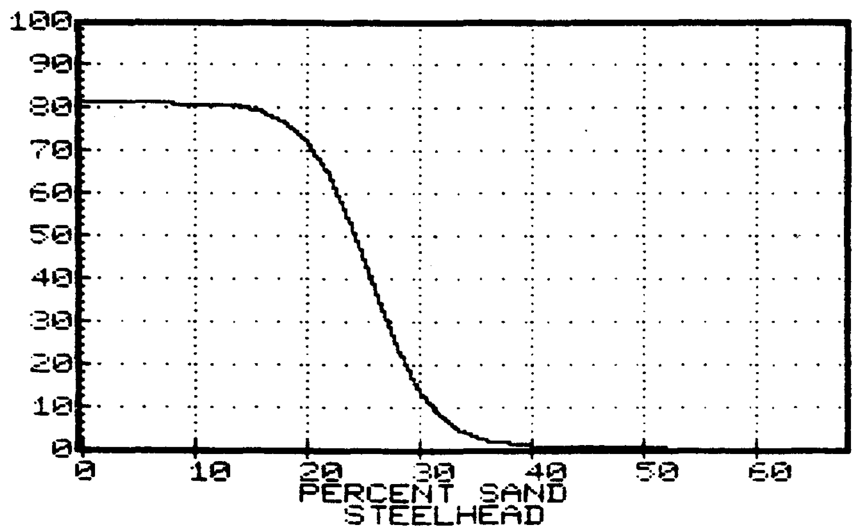

100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
PERCENT SAND
STEELHEAD

Figure 3

USE OF THE CURVES:

These curves must be used only with CAUTION! As can be seen from Figure 1, there is substantial variability in the data. Therefore, it is NOT appropriate to use the curves without taking this variability into account.

The upper halves of Figures 2 and 3 provide the information necessary to use the curves, while accounting for the uncertainty in them. The solid lines represet the upper and lower 95% predictive confidence intervals on the functions. For a given percent sand, a line drawn straight up will intersect the two solid-line curves. Where this vertical line crosses the solid curve, a horizontal ine can be extended to the left until it crosses the Y-axis. The point where it crosses will be the corresponding fry emergence. Thus, you will obtain two values of fry emergence for each vale of percent sand. These two fry emergence values are the 95% confidence limits.

For example, 40% sand will correspond to somewhere between 0% and 55% fry emergence in Chinook salmon. These limits may seem quite wide, but they reflect the TRUE information content of the data. It would be inappropriate to try to say more.

The lower graphs of Figures 2 and 3 show the plotted function without any indication of variability. Although it is tempting, it would be risky to use them.